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Arthur Marshall

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A SHORT ACCOUNT OF EXPLOSIVES

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A Short Account of Explosives

BY

ARTHUR MARSHALL

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Chemical Inspector, Indian Ordnance Department

Author of "Explosives, their History and Manufacture, Properties and Tests"

WITH 29 ILLUSTRATIONS.

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To Field-Marshal

SIR DOUGLAS HAIG,

K.T., G.C.B., K.C.I.E., G.C.V.O.

Commanding-in-Chief

BRITISH ARMIES IN FRANCE.

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PREFACE

IN this little book I have endeavoured to present in a clear and simple manner the main facts concerning explosives and their properties in the hope that it may be of use to the officers of our now mighty army and also to naval officers and the large numbers of men and women who have to deal with explosives in the manufacture of munitions and other ways. The subject of explosives is such a wide one that it has only been possible to deal with the main facts, and these only briefly, but I hope that those who read through these pages will carry away a clear conception of the different varieties of explosives. The most recent facts have been included so far as the interests of the State permit.

A. MARSHALL.

NAINI TAL, INDIA.

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CHAPTER I

INTRODUCTORY

An explosive is a material which is capable of giving off a very large volume of gas very suddenly; at the same time it always evolves a great deal of heat. The gas which is thus suddenly formed tends naturally to expand, and in so doing to overcome the resistance of anything which opposes the expansion. The sharp noise, which is always associated with an explosion, is due to this sudden evolution of gas. Heat is liberated at the same time, and this produces a bright light; it also increases the expansion of the gas.

A great many explosives are now known, and they may be divided into classes in various ways according as one considers their composition, their properties or their uses. Some are single substances from the chemical point of view, such as nitroglycerine or fulminate of mercury; others are mixtures, of which the most familiar example is ordinary gunpowder (black powder). In mixed explosives some or all of the ingredients may be themselves explosive. Some explosives are very violent, detonating at the rate of several miles per second; these are termed high explosives. Others burn comparatively slowly and are used to propel a bullet or shell from a fire-arm; these are the smokeless powders. Black powder occupies a position between these two classes.

Some can be exploded directly by the application of a spark or friction; gunpowder, if in a fine state of division, can be ignited by a spark, fulminate of mercury either by a spark or a blow or friction. Other explosives require a small quantity of an explosive of the last kind to send them off satisfactorily; high explosives are usually detonated by means of a detonator charged with fulminate; smokeless powders also are generally provided with a small igniting charge of a more sensitive explosive.

There are various special sorts of explosives used for special purposes. For instance, there are "safety" explosives used in coal mines; these are mostly high explosive mixtures so composed that they do not give a hot flame which will set light to "fire-damp" or a mixture of coal dust and air. Fireworks are charged generally with slow burning mixtures resembling gunpowder more or less.

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Of the various physical properties of an explosive, one of the most important is its sensitiveness. It must be sufficiently sensitive to be fired with certainty by the means to be used, but up to this limit the less sensitive it is, the safer and therefore the better it is. An explosive that is very sensitive to blow or friction is too dangerous for use. The hardness, consistency and form of grain are all of importance as they affect the explosive properties.

Other important properties are the power and violence of the explosive. The power is the quantity of work that the explosive can do. The violence depends not only on the power, but also on the time in which the energy is set free.

All these matters will be discussed in the following pages in which technical details will be avoided as far as possible. For fuller information I would refer the reader to my larger work on *Explosives, their History and Manufacture, Properties and Tests*.[1]

[1] J. & A. Churchill—2nd Edition, 1917.

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CHAPTER II

BLACK POWDER AND SIMILAR MIXTURES

GUNPOWDER, otherwise black powder, is by far the oldest of all explosives. It seems to have been made and used first in the East in the first half of the thirteenth century. It is a mixture of saltpetre, charcoal and sulphur. Of these charcoal, formed by heating wood, must have been familiar to man from the very earliest times. Sulphur occurs in the native state in various volcanic regions, especially in Sicily, and can be refined fairly well by merely melting it and running it off from the earthy matter. Saltpetre also occurs naturally in the salty efflorescences that are formed on the surface of the ground in places where there is little or no rainfall during a considerable portion of the year. But saltpetre is only one of many substances that may be present in these efflorescences, and a considerable amount of knowledge and experience were required before it was possible to recognise the substance and separate it in a state of sufficient purity. The discovery of gunpowder is therefore intimately connected with that of saltpetre. It appears to have been made first in China, but knowledge of it spread rapidly to the West, being carried perhaps by the armies of the Mongols, which in the thirteenth century overran Asia from China to Mesopotamia and Russia. From there it was carried by the Arabs through Egypt and Northern Africa to Spain, and so the secret was learnt by Europeans. From the writings of Roger Bacon about the year 1250 it is evident that he was familiar with gunpowder and some of its properties. The early history of this subject is, however, far from clear, for many of the statements are purposely obscure, and most of the words used in the various languages as names of gunpowder, saltpetre, etc., had previously been employed in other senses.

At first gunpowder was only used for making fireworks, such as squibs, and perhaps incendiary mixtures. In warfare these were probably effective in frightening the enemy rather than in doing him real injury.

The further step of using gunpowder to drive a missile from a fire-arm does not appear to have been made until some time in the first half of the fourteenth century. This invention required a considerable degree of engineering skill. It has often been ascribed to a German monk called Berthold Schwartz, but nothing is known with certainty of this individual, and the dates given vary considerably, but are all in the second half of the four-

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teenth century and are consequently all too late. By the middle of this century all the countries of Western Europe seem to have possessed fire-arms, but of course they were of a very rudimentary description.

In the course of the following centuries the methods of manufacture of gunpowder were gradually improved. At first the three ingredients, with or without other additions, were simply pounded up together in a mortar. As the scale of manufacture increased the occurrence of serious accidents rendered it necessary to erect special powder mills remote from dwelling-houses. The composition of the powder, which was at first very variable, gradually became fixed at about 75 per cent. saltpetre. In England and France respectively the standard mixtures are:

	England	France
Saltpetre	75	75
Sulphur	10	12·5
Charcoal	15	12·5

In the other countries the compositions are very similar.

The preparation of the ingredients was also gradually perfected and became standardised more or less. The charcoal for the best sorts of gunpowder is made by heating selected sorts of wood in iron cylinders with only small openings to permit the escape of the gases and vapours. Dogwood, alder and willow are those most used.

The sulphur is refined by distilling it, collecting it in the molten state and casting it into sticks or "rolls." "Flowers of sulphur," the small crystals obtained by subliming sulphur, are not used for the manufacture of good class explosives, as they always contain acid. Until recently nearly the whole of the world's supply of sulphur came from Sicily from the slopes of Mount Etna, but now very large quantities are obtained from Louisiana in the United States, where it is worked by the ingenious Frasch process. The sulphur which lies at a considerable depth is melted by means of superheated water, which is passed down through pipes. Air is also pumped down through a smaller pipe concentric with the first, and the molten sulphur and air rise through another still smaller pipe inside the last.

The saltpetre is refined by making a hot saturated solution and allowing it to crystallise out. As saltpetre is much more soluble in hot than in cold water it is possible in this way to separate it almost completely from the impurities. In India a large industry has grown up, especially in Bihar and the Punjab, of recovering saltpetre from the earth in the neighbourhood of village sites, where it is formed by the action of bacteria on nitrogenous material, such as excreta. During the dry season the natural rise of the water in the soil, and its evaporation at the surface, causes deposits to be formed of saltpetre and other soluble salts. In Europe saltpetre was formerly obtained either by working up scrapings from stables, cellars, dove-cots, etc.,

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or from artificial nitre beds, or plantations, where nitrogenous matter was subjected to bacterial action. In the latter part of the nineteenth century, however, these were entirely displaced by "conversion" saltpetre made by the interaction of sodium nitrate, obtained from Chili, and potassium chloride, obtained from the mines at Stassfurt in Germany.

Before the introduction of smokeless powders the best sorts of gunpowder, either for military use or for charging sporting guns and rifles, were manufactured by a series of operations comprising the following stages. The method is still in use for the best gunpowder.

(1) The three ingredients are ground separately in mills of various types, and sifted.

(2) They are weighed out in the right proportions and mixed roughly in a machine containing arms which rotate rapidly.

(3) They are incorporated together in an edge runner mill. This consists of a horizontal circular bed on which rotate two cylindrical runners weighing several tons each. The charge is 60 to 80 lbs. of powder, which is kept moist during the milling operation, lasting 3 to 8 hours; the longer the incorporation the faster does the powder burn.

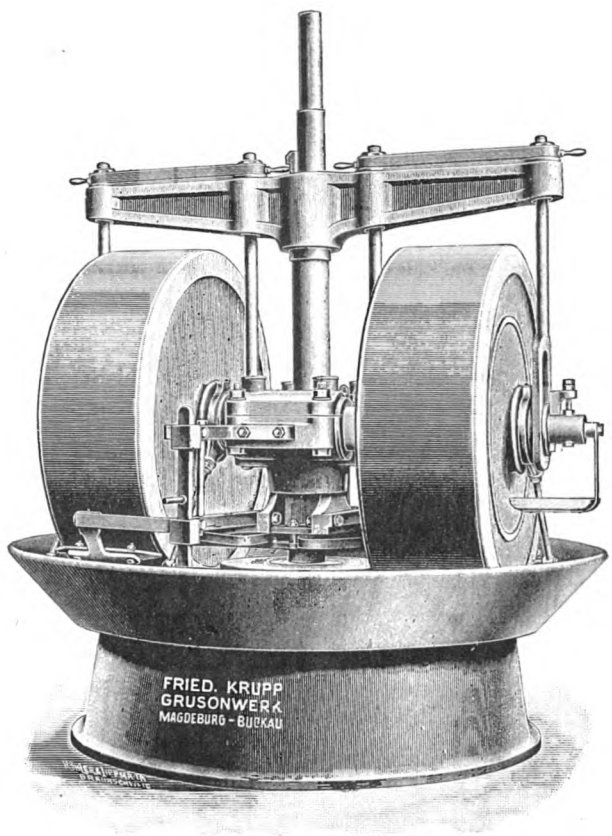

FIG. 1. Gunpowder Mill

(4) When this operation is finished the "mill-cake" is removed by means of wooden shovels and tools and taken to another house where the large lumps are broken down by hand with wooden mallets or by passing the material through gunmetal rolls.

(5) It is then pressed to increase the density and prevent the ingredients separating again from one another. For this purpose the broken down mill-

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cake is spread out in layers, each layer being separated from the next by a plate of gunmetal. The whole is then pressed by means of a powerful hydraulic press.

(6) The next operation is corning or granulating. This consists of passing the mill-cake through a series of rollers which break it down to grains of the required size. As it comes away from the rollers it is automatically sifted and the coarse material is returned through the rollers again. The material that is too fine is milled again for a short time and then passes through the same series of operations.

(7) After this the granular material is passed through a rotating cylindrical sieve or slope reel covered with fine wire gauze. The dust is thus removed.

(8) Then it is polished or glazed by rotating it in a wooden drum. Cannon powders received an addition of graphite which made them burn more slowly.

(9) Next it is dried in a stove, and finally it is again dusted, and blended into large uniform batches.

This scheme has been modified in various ways. Pebble powder for heavy ordnance was made by cutting sheets of press-cake into cubes which were then glazed. Prism powder for still larger guns was made by pressing into hexagonal prisms in a special machine. In prism brown powder a special brown charcoal was used made from straw.

Most of the gunpowder made nowadays is used for blasting purposes, and for this it is not necessary to adopt such an expensive process of manufacture. In France mining powder is only milled for half an hour. Mining powders do not require to be granulated so carefully as those used in fire-arms, and the pressing operation is sometimes omitted entirely.

For saltpetre (potassium nitrate) the cheaper sodium salt (Chili saltpetre) is sometimes substituted. Spreng-salpeter, an explosive much used in the Stassfurt salt mines, is an explosive of this kind. It is more powerful than ordinary gunpowder but less violent. The presence of sodium nitrate makes the powder hygroscopic. That is, it tends to absorb moisture from the air and become wet, but this is a difficulty that can be overcome by providing the blasting cartridges with suitable wrappers.

An explosive which is used very largely in coal mines in England is Bobbinite, which has approximately the composition:

Saltpetre	66
Charcoal	20
Sulphur	2
Starch	9
Paraffin Wax	3

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CHAPTER III

NITROCELLULOSE

GUNCOTTON, a variety of nitrocellulose, was discovered in 1845–46 by Professor Schönbein of Basle by the action of a mixture of nitric and sulphuric acids on cotton. The importance of the invention was recognised immediately and attempts were made by the governments in various countries to develop it for military purposes, but a series of serious explosions in England, France and Austria caused the manufacture to be dropped again after a short time. In 1865, however, Sir Frederick Abel discovered that guncotton could be made satisfactorily stable if it were reduced to pulp in a beating machine and thoroughly washed with water. Shortly afterwards the practice was adopted of boiling the guncotton with several changes of water. Sir Frederick Abel also introduced the use of cotton waste instead of raw cotton for the manufacture of guncotton. Formerly the nitration of cotton was carried out in small earthenware pots. The purified cotton waste after being picked over and passed through a teazing machine to open it up was dried and weighed out into uniform quantities of about 1¼ lbs. Each of these was then immersed in a strong mixture of sulphuric and nitric acids. After remaining in this for a few minutes it was lifted out by means of an iron or aluminium prong, placed on a grating over the back of the pan and pressed with the aid of a lever in order to remove the greater part of the excess of acid. Then the sodden mass, which consisted of partially nitrated cotton together with about eleven times its weight of mixed acid, was put into an earthenware pot, which was covered with an earthenware lid and placed in a large trough of cold water together with numerous other similar pots. After remaining in this for 12 to 24 hours the pot was seized by a boy with a pair of tongs and tipped into a centrifugal machine together with the contents of several other pots. The centrifugal machine was then rotated rapidly to remove the greater part of the waste acid. The guncotton was taken out and immersed quickly in a large bulk of running water. After being washed for some time with cold water it was transferred to large wooden vats where it was boiled for some days with several changes of water.

One of the objections to this process was the large amount of hand labour involved, during which the workers were exposed to acid fumes. The con-

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tents of the pots often fumed off, especially in hot weather, giving off large volumes of red fumes which obliged all the workers to leave the building until the fumes had cleared away again. The contents of the centrifugals also fumed off sometimes.

In Germany a method was adopted of nitrating in the centrifugal machine

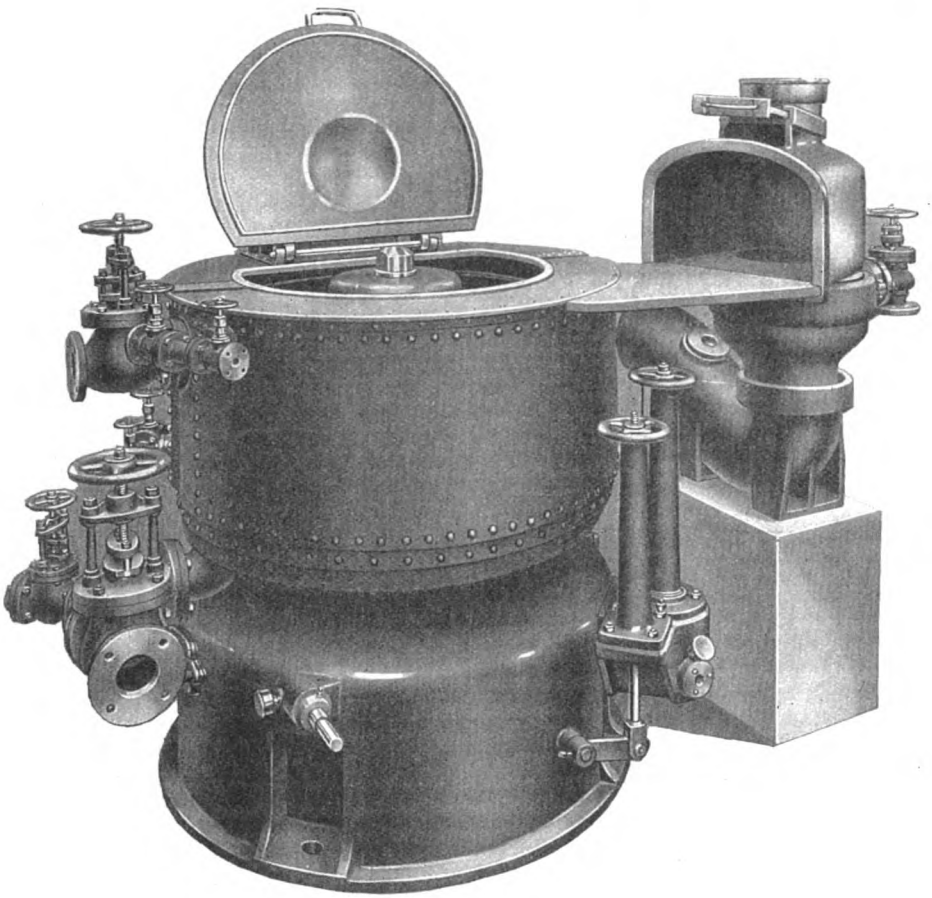

FIG. 2. Nitrating Centrifugal for making Nitro-cotton (Selwig and Lange)

itself. This method, which is not much used in England, saves much labour but does not readily yield guncotton containing a high percentage of nitrogen, as it is not practicable to leave the cotton in the acid for more than about an hour. The process has been improved by providing for the agitation of the acid in the centrifugals and the transference of the wrung-out gun-cotton directly into running water which carries it away to washing tanks.

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At the Royal Gunpowder Factory, Waltham Abbey, another process was worked out by W. T. and J. M. Thomson and Sir F. Nathan and is known as the "displacement process." The cotton is nitrated in shallow circular pans constructed of earthenware or, in some recent installations, of special acid-resisting iron. Over the bottom is a perforated plate, and the pan is filled up to a certain level with mixed acid. In this dried cotton waste is immersed, then other perforated earthenware plates are laid on the top of it and water is cautiously run on so as to cover it with a thin layer. As the water is considerably lighter than the acid hardly any mixing takes place.

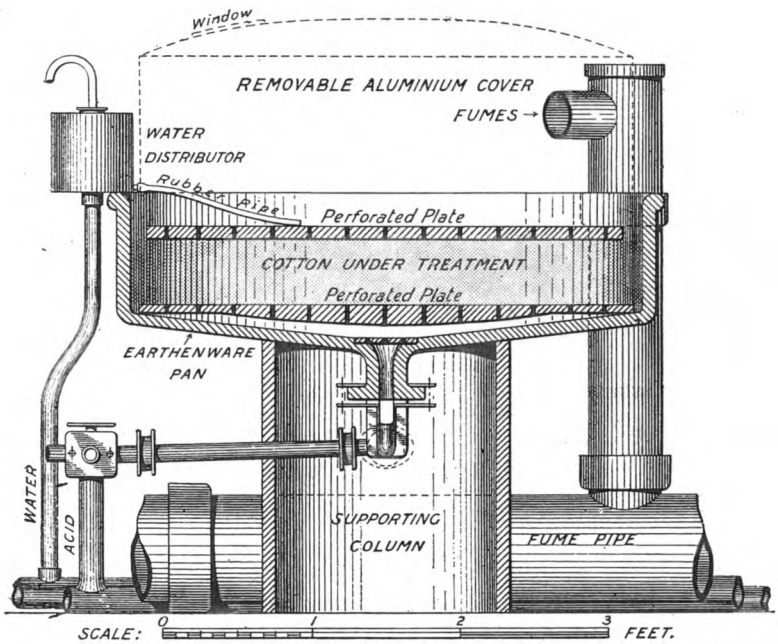

FIG. 3. Section of Displacement Apparatus (from *Arms and Explosives*)

During the immersion of the cotton the pan is covered with an aluminium hood connected through a broad pipe to a fan to carry away the acid fumes. When the acid has been covered with water, this hood is no longer necessary and is removed. The nitration is allowed to proceed for 2½ hours. Then the acid is run off slowly from the bottom and at the same time water is run in gently at the top, so that the acid is gradually displaced by water. When the displacement is complete the flow of water is continued at a greater rate, until practically all the acid has been washed out of the guncotton, which is then transferred to the boiling vats.

The boiling is carried out in large wooden vats which hold about a ton

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of guncotton each. The vat has a false bottom. After the washed guncotton has been placed in it, it is filled with water which is then boiled by blowing in live steam. After a time this is run off and fresh water is run in which is boiled in the same way. It is important that the first waters should be slightly acid as this stabilises the guncotton better, but the acid given off by the guncotton is sufficient to provide the requisite degree of acidity. The last boilings should be slightly alkaline so as to remove the last traces of acidity from the material. A hard water is best as the calcium bicarbonate in it neutralises the acid, and when boiled deposits calcium carbonate on the fibres of guncotton, thus adding to its stability.

The guncotton at this stage differs very little in appearance from the original cotton waste. The fibrous structure is very little affected by the operations of nitrating and boiling. It is next transferred to a beater similar to those used for making paper pulp. This machine consists of an oval trough on one side of which is mounted a drum which rotates on a horizontal

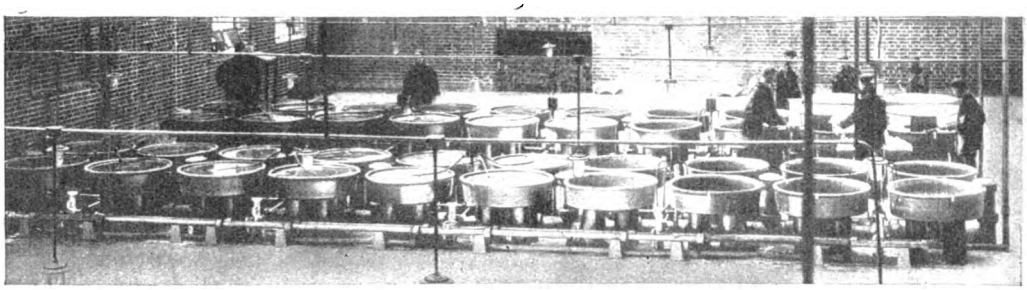

FIG. 4. View showing Arrangement of Units in Rows (from *Arms and Explosives*)

axis and carries a large number of knives set radially. In the bottom of the trough there are a number of fixed knives which almost touch the knives on the drum as it rotates, and the guncotton, as it passes together with a large bulk of water between these fixed and moving knives, is cut into short lengths and so is reduced to pulp. The pulp is run through a series of traps which remove grit and other impurities, and between powerful electromagnets which extract particles of iron derived from the knives of the beater or other source. Then the pulp is washed well with several changes of water. Finally the greater part of the water is removed by means of centrifugal machines or special presses, and the guncotton is then ready to be conveyed to another part of the factory where it is converted into the finished explosive.

The properties of the nitrocellulose depend upon the composition of the mixed acid used and also to some extent on the sort of cellulose. The nitrocelluloses differ in the amount that is soluble in a mixture of ether and alcohol,

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and in the percentage of nitrogen that they contain. The highest nitrated product that can readily be produced contains about 13·5 per cent. nitrogen and is almost insoluble in ether-alcohol. The guncotton used in the British service as a high explosive and for making cordite contains 13 per cent. nitrogen and about 10 per cent. of matter soluble in ether-alcohol. This is made from cotton waste with an acid containing about 71 per cent. sulphuric acid, 21 per cent. nitric acid and 8 per cent. water. If the percentage of water in the acid be increased the percentage of nitrogen falls and the solubility rises, but by varying the proportion of sulphuric to nitric acid it is possible to obtain nitrocelluloses of the same degree of solubility, but very different

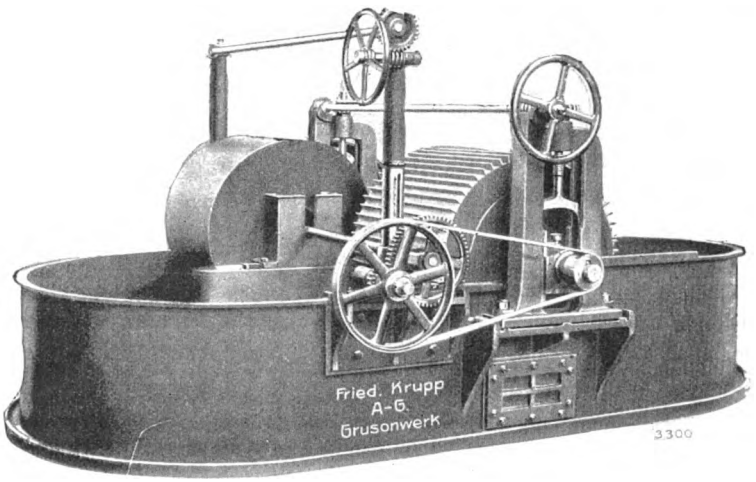

Fig. 5. Beater for Pulping Gun-cotton

percentages of nitrogen. The power of the material as an explosive increases with the percentage of nitrogen.

The French military smokeless powder, Poudre B, is made from a mixture of two nitrocottons one of which is similar to English guncotton; the other is a nitrocotton entirely soluble in ether-alcohol and containing about 12 per cent. nitrogen. The Russian and American Governments, on the other hand, use for their smokeless powder a single soluble nitrocellulose containing the highest practicable percentage of nitrogen. Nitrocellulose of this description is called "pyrocollodion." That used by the Americans contains about 12·5 per cent. nitrogen and is made by means of a mixed acid containing 15 per cent. of water and about three parts of sulphuric acid by weight to one of nitric. Some other smokeless powders, military and sporting, are made from nitrocelluloses which are partially soluble in ether-alcohol.

The solution of nitrocellulose in ether-alcohol is called collodion, and the

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soluble nitrocellulose collodion cotton. This solution is used for various purposes, such as the manufacture of lacquers and artificial silk and for coating incandescent gas mantles. A special variety of it is used for the manufacture of blasting gelatine; and this must be of such a nature that a small proportion of it will convert nitroglycerine into a stiff jelly; it is not made from cotton waste but from "cop bottoms." It contains 11·5 to 12 per cent. nitrogen.

The cotton waste that is to be nitrated must first be purified. It is obtained mostly from spinning mills and consists of tangled ends of cotton together with fluff or "fly." It is picked over by hand and extracted, if necessary, with benzene or other suitable solvent to remove fat and oil. It is also boiled with a dilute solution of soda to free it from various impurities, washed with water and sometimes bleached with bleaching powder, washed again and dried.

Another sort of cotton which is often used, but not to any great extent in England, is "linters," which consists of the short fibres that are obtained from the bolls of some varieties of cotton after the lint has been removed by the gins.

Fairly good cellulose can be made from wood fibre by treating it with chemicals. Processes of this sort are in use on a very large scale for the preparation of raw material for the manufacture of paper. There is reason to believe that the Germans are using wood cellulose for the manufacture of their smokeless powders now that their supplies of cotton have been cut off.

Cellulose belongs to the class of substances known as colloids, which possess various peculiar physical and chemical properties that render it practically impossible to purify them completely. Cotton is one of the purest forms of cellulose. Nitrocellulose is also a colloid.

Nitric and sulphuric acids are used in the manufacture not only of nitrocellulose but also of many other explosives. Hence the manufacture and supply of these acids is a matter of great importance in war time. Sulphuric acid is not actually consumed in the nitration process, but it is never possible to recover the whole of it. Moreover very large quantities of sulphuric acid are used up in the manufacture of nitric acid from Chili saltpetre.

The function of the sulphuric acid during nitration is to combine with the water that is formed in the process and so prevent the dilution of the nitric acid, but it may also assist in other ways. Without its use satisfactory nitration products could not be obtained and the loss of the comparatively expensive nitric acid would be considerably greater.

Sulphuric acid is made from sulphide ores or, more rarely, from sulphur. There are two methods of manufacture, the chamber process and the contact process. The former yields an acid of 70 to 80 per cent. strength, which

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requires to be concentrated before it can be used for the manufacture of most explosives.

The contact process on the other hand yields fuming acids containing considerable proportions of sulphuric anhydride, and consequently it can be used to great advantage to strengthen up weak waste acids. This fuming acid is often called "Oleum" or N.O.V.

Nitric acid is made by the action of sulphuric acid on sodium nitrate (Chili saltpetre or nitrate).

$$\underset{\text{Sulphuric acid}}{H_2SO_4} + \underset{\text{sodium nitrate}}{NaNO_3} = \underset{\text{nitric acid}}{HNO_3} + \underset{\text{sodium bisulphate}}{NaHSO_4}$$

The nitrate and the sulphuric acid are placed together in a large cast-iron still which is then heated. The nitric acid is driven off in the form of vapour and is condensed and collected. In the still remains a molten mass consisting mostly of sodium bisulphate. This is run off and allowed to solidify and is known as "nitre-cake." As it is strongly acid it can be used as a substitute for sulphuric acid in many industries.

Nitrogen is the largest constituent of the atmosphere, and of late years a number of processes have been developed for the manufacture of nitric acid and nitrates from this inexhaustible source. The discussion of these processes is beyond the scope of this book, but Germany is now entirely dependent upon them for the supply of this essential material, and a number of immense plants for the manufacture of nitric acid from the atmosphere have been erected there since the beginning of the War.

Cotton is so bulky that it is necessary to use a very large proportion of acid for the nitration. In the displacement process about thirty-three parts of mixed acid are present for every part of cotton, and in the nitrating centrifugal fifty parts of acid. Only a small proportion of the nitric acid is consumed and none of the sulphuric. Most of the acid is recovered as "waste acid," and this can be revivified by the addition of strong sulphuric and nitric acids and used over again. In the nitration of other substances such as glycerine and toluene waste acid is also obtained, but not in the same proportion. In some cases it can be revivified and used again; in others it is necessary to separate the constituent acids and recover them separately. The nitric acid can in some cases be distilled off, condensed and used again, and the sulphuric acid left in the still can then be reconcentrated or strengthened up by the addition of oleum. In other cases it is necessary to denitrate the waste acid by passing it down a tower where it meets a current of steam, which drives off and decomposes the nitric acid and dissolved nitro-bodies and carries the compounds of nitrogen to condensers and towers where they are recovered as weak nitric acid. From the bottom of the tower runs a

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stream of weak sulphuric acid which is reconcentrated so that it can be used again.

The early attempts to make a smokeless powder from nitrocellulose were failures and consequently guncotton was used only as a blasting explosive, especially for military demolitions. It is still used to some extent for this purpose. The moist guncotton is moulded into blocks in a hydraulic press and is then placed in a much more powerful press, where it is subjected to a pressure of four to seven tons per square inch. It is thus converted into a substance of the consistency of wood containing about 15 per cent. of water, which is decidedly insensitive and therefore safe. To detonate it, use is made of a small primer of dry compressed guncotton, which in turn is detonated by means of a detonator containing fulminate of mercury. These primers are made in a similar manner to the slabs of wet compressed guncotton but are afterwards dried in a stove.

The principal use of nitrocellulose as an explosive is, however, for the manufacture of smokeless powders and for the preparation of composite explosives. Large quantities of collodion cotton are also used in the arts of peace; it is a constituent of celluloid.

Guncotton does not contain sufficient oxygen to convert all the carbon in it into carbon dioxide and all the hydrogen into water vapour. Consequently its power can be utilised more completely if it be mixed with an oxidising material such as saltpetre or barium nitrate. The explosive thus made is called Tonite. That manufactured by the Cotton Powder Co. consists of equal parts of guncotton and barium nitrate, and is made in the form of cylindrical compressed cartridges, but it is not used very much now.

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CHAPTER IV

NITROGLYCERINE AND NITROGLYCERINE EXPLOSIVES

NITROGLYCERINE was discovered by Sobrero in 1846, and its manufacture on a considerable scale was started by Alfred Nobel near Stockholm in 1862. The transport of this liquid explosive led, however, to numerous explosions and its introduction was forbidden in many countries. In 1867 Nobel discovered that kieselguhr was capable of absorbing three times its own weight of nitroglycerine and that the plastic product thus obtained, dynamite, was comparatively safe. This led to a great development of the nitroglycerine industry. In 1875 Nobel invented blasting gelatine, which is nitroglycerine converted into a stiff jelly by the addition of about 8 per cent of collodion cotton.

The nitration of glycerine is carried out in large lead vessels provided with cooling coils through which cold water is circulated, and with perforated pipes through which air is blown to keep the contents in a state of violent agitation. The glycerine is introduced gradually in the form of a fine spray. When it has all been introduced the nitroglycerine is allowed to separate from the acids and is then run off and washed. Formerly the nitration and separation were carried out in separate vessels, but in most factories both operations are now performed in the nitrator-separator of Nathan, Thomson and Rintoul shown in Fig. 6. The mixed acids are introduced through the pipe *d*, and are agitated by means of air blown through the perforated pipe *g* and kept cool by water circulated through the coils *h*. The injector for glycerine is inserted through the top *e* and the flow is regulated so that the temperature never exceeds 22° C. When the nitration is complete, the injector is removed, and the temperature, as shown by the large thermometer *S*, is reduced to 15°. Some waste acid from a previous charge is run in through *d* until the surface of the liquid in the vessel rises to the level of the windows *f*. The nitroglycerine, being lighter than the acid, floats to the surface. When a sufficient quantity has collected, a little more waste acid is admitted through *d*, and this causes the nitroglycerine to run over down the pipe *k* into the pre-wash tank. This is continued until all the nitro-

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glycerine has been displaced into the pre-wash tank. The waste acid is then run off through a branch pipe and the nitrator-separator is then ready to start a fresh charge. Another pipe leads to the drowning tank to which the charge is run in case of an accident. The pipe *m* is to carry off the air and fumes.

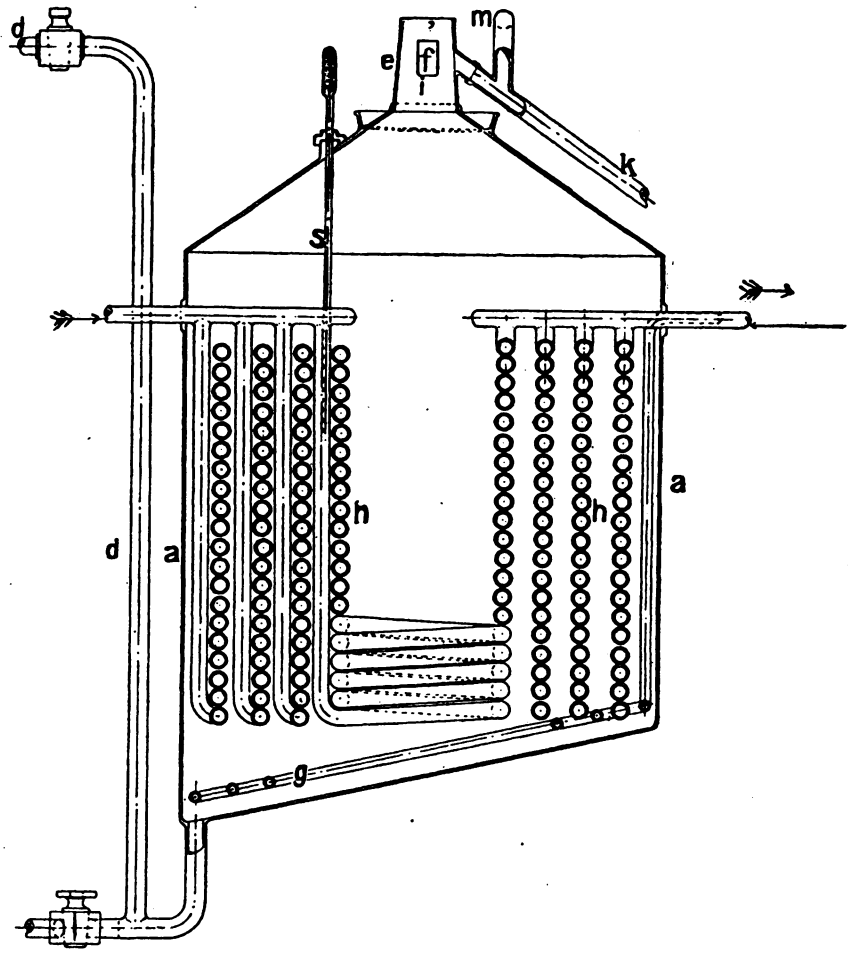

FIG. 6. Nitrator-Separator for making Nitroglycerine

The pre-wash tank is an open circular lead vessel. The bottom slopes down to one side, and at the lowest point there is an orifice to which is connected a large rubber tube for running off the nitroglycerine. There is another orifice which is connected inside the tank with a rubber tube which is used to skim off the washing waters which, being lighter than the nitro-

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glycerine, separate out above it. To the bottom of the tank are burnt air pipes so that the contents can be agitated by means of compressed air.

In the pre-wash tank the nitroglycerine is washed with several changes of water and then with a dilute solution of sodium carbonate to remove the greater part of the acid which has been carried over by the nitroglycerine. The nitroglycerine is then run through a lead gutter to the final washing house, where its purification is completed in a vessel similar to the pre-wash tank. It is here washed with several changes of dilute soda solution and then with water. It should then be slightly alkaline. It is passed through dry sponges to remove water and is then ready to be mixed with other substances for the manufacture of composite explosives.

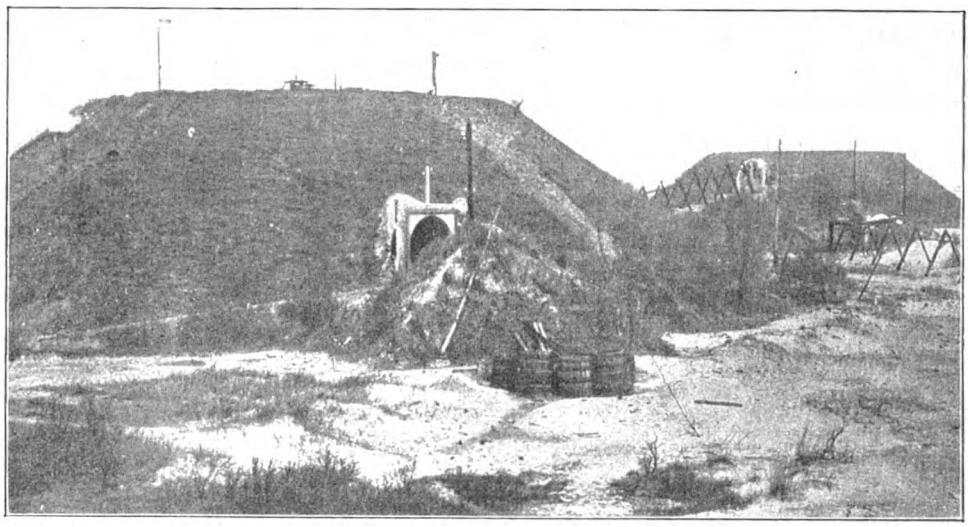

FIG. 7. Nitro-glycerine Factory (from *Fabrication des Explosifs*, Brussels, 1909)

Nitroglycerine is a heavy oily liquid. It is slightly volatile and somewhat poisonous, and causes acute headaches to those who are not accustomed to handling it. It is liable to freeze to a crystalline solid if cooled below 13° C. (56° F.). This is a source of considerable inconvenience and danger, and additions are frequently made to nitroglycerine blasting explosives to render them less liable to freeze.

The nitration of glycerine is represented by the equation:

$$C_3H_8O_3 + 3\,HNO_3 = C_3H_5N_3O_9 + 3\,H_2O$$

Glycerine	Nitric acid	Nitro-glycerine	Water

Dynamite No. 1 is made by mixing nitroglycerine with a third of its

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weight of kieselguhr. This is a silicious material consisting of the remains of microscopic animals, and is purified and dried by heating it to a high temperature. It is mixed with the nitroglycerine and after standing for some time the two materials are kneaded together by hand. Dynamite is a thick pasty material, only slightly plastic; it is made into cylindrical cartridges by pressing it through a tube into a wrapper of vegetable parchment. Dynamite is often coloured red by the addition of a little oxide of iron to the kieselguhr. A small percentage of calcium carbonate or other alkaline substance is also added generally to increase the stability. Formerly most of the kieselguhr came from Germany, but there are deposits in Scotland, Australia and other countries, and these are now being developed. Kieselguhr dynamite is not used very much now as there are other more powerful and more economical explosives available. The presence of 25 per cent. of inert material in it involves a considerable loss of power, and the nitroglycerine contains slightly more oxygen than is necessary for the total combustion of the products of explosion, as is shown by the equation:

$$4\,C_3H_5N_3O_9 = 12\,CO_2 + 10\,H_2O + 6\,N_2 + O_2$$

Nitroglycerine — Carbon dioxide — Water vapour — Nitrogen — Oxygen

Another disadvantage of kieselguhr dynamite is that, if it gets wet, the nitroglycerine is displaced from it by water and, oozing out of the packing cases, may constitute a serious danger.

In America this explosive is called Giant powder and the term dynamite is usually applied to a mixture of nitroglycerine, wood pulp and sodium nitrate, which is not authorised in England at all. As wood pulp and sodium nitrate are inexpensive materials these American dynamites are comparatively cheap. The wood pulp acts not only as an absorbent for the nitroglycerine, but also as a combustible material which in the explosion is oxidised by the oxygen of the nitrate and the excess of oxygen in the nitroglycerine. These dynamites are made in various grades distinguished from one another by the percentage of nitroglycerine they contain. The greater the percentage of nitroglycerine the more violent and powerful is the explosive.

The following are examples of these American "straight" dynamites:

Grade	40 per cent.	60 per cent.
Nitroglycerine	40	60
Wood pulp	13	17
Sodium nitrate	46	22
Calcium or Magnesium carbonate .	1	1

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but the compositions vary considerably. The explosives works in the United States also make "ammonia" dynamites in which about half the nitroglycerine is replaced by ammonium nitrate, and low-freezing dynamites in which about a third of it is replaced by dinitrotoluene or other similar substance to prevent the nitroglycerine freezing easily. The weaker grades of American dynamite frequently contain sulphur, resin and flour in replacement of part of the wood pulp.

In South Africa explosives are made similar to American straight dynamite and are sold under various names such as "ligdyn."

An explosive of a somewhat different type which is also used in America is Judson powder, which is a sort of crude gunpowder coated with a small proportion of nitroglycerine to render it more violent. The composition of one of the grades is approximately:

Nitroglycerine	5
Sulphur, coal and resin	35
Sodium nitrate	60

The nitrate is mixed with the combustibles and the mixture is heated beyond the melting point of the sulphur and resin. When this is cold the nitroglycerine is added to the slightly porous granular mass.

To make blasting gelatine the nitroglycerine is mixed with about 8 per cent. of dried collodion cotton in a brass-lined box and allowed to stand over night. Next day it is taken to the mixing house where it is warmed to about 40° C. (104° F.) and stirred mechanically for an hour under special precautions. After standing for some time it is taken to the cartridge hut where it is passed through a simple machine provided with an archimedean screw worked by hand which squirts it out like a sausage. Suitable lengths of this are broken off and wrapped in vegetable parchment. Blasting gelatine is a very powerful and violent explosive containing just about the right proportion of oxygen for total oxidation. It is, however, comparatively expensive, and to develop its full violence it requires a primer of dynamite or other easily detonated explosive, especially if it be rather old. For these reasons it is not used so much as some other explosives containing a nitrate and a combustible material such as wood meal in addition to the constituents of blasting gelatine. Of these, gelignite, containing about 60 per cent. of nitroglycerine, is the one most used in Great Britain. Gelatine dynamite is intermediate between this and blasting gelatine. Dynamite No. 4 or 40 per cent. dynamite is a lower and cheaper grade containing sodium nitrate instead of saltpetre. The following may be taken as typical analyses of these explosives:

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	Blasting gelatine	Gelatine dynamite	Gelignite	Dynamite No. 4
Nitroglycerine	91·5	74·5	60·5	39
Collodion cotton	8	5·5	4·5	1
Wood meal	—	4	7	17
Potassium nitrate	—	15·5	27	—
Sodium nitrate	—	—	—	41
Calcium carbonate	0·2	0·2	0·2	0·2
Moisture	0·3	0·3	0·8	1·8
	100	100	100	100

These explosives are made in much the same way as blasting gelatine, the wood meal, nitrate, etc., being added to the nitroglycerine and collodion cotton after these have been well mixed. The object of thickening the nitroglycerine with collodion cotton is to prevent it exuding from the explosive or being displaced by water.

The Americans make gelatine dynamites of various grades, of which the following are examples:

Grade	40 per cent.	60 per cent.
Nitroglycerine	33	50
Collodion cotton	1	2
Sodium nitrate	52	38
Combustible material	13	9
Calcium carbonate	1	1

The combustible material often consists of sulphur, flour and resin in addition to wood meal. Sulphur is, however, an objectionable ingredient as it forms poisonous products in the explosion, and it may lower the stability of the explosive.

Nitroglycerine is also a constituent of many other commercial high explosives, and of an important class of smokeless powders which will be dealt with in Chapter VII.

For use in coal mines explosives are required which will not ignite a mixture of fire damp and air, or coal dust and air. They must, therefore, only give a small flame on explosion, and this effect may be produced by the addition of a cooling agent such as ammonium oxalate. An explosive of this type which has been much used is Samsonite:

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Nitroglycerine	58·5
Collodion cotton	3·5
Potassium nitrate	18·0
Wood meal	6·5
Ammonium oxalate	13·5

Others were Saxonite, Arkite and Swalite. A few years ago a more severe test was introduced for these coal mine explosives and it became necessary to increase the percentage of oxalate and nitrate:

	Arkite No. 2	Duxite
Nitroglycerine	32	32
Collodion cotton	1	1
Potassium nitrate	27	—
Sodium nitrate	—	28
Wood meal	10	10
Ammonium oxalate	30	29

One of the earliest and most successful coal mine explosives was Carbonite, which contains such a high percentage of wood meal that most of the carbon in it is only oxidised to monoxide and consequently the heat formed is not very great. The composition of this explosive has been varied somewhat, but generally it is approximately:

Nitroglycerine	25·0
Potassium nitrate	30·5
Barium nitrate	4·0
Wood meal	40·0
Soda	0·5

This was formerly on the English Permitted List, as also were other explosives of the same type, such as Tutol and Kolax, but to pass the more severe Rotherham test it has been necessary to add ammonium oxalate:

	Super-Kolax No. 2	Britonite No. 2
Nitroglycerine	28·5	24
Collodion cotton	1·0	—
Potassium nitrate	16·5	30
Barium nitrate	5·0	—
Wood meal	31·0	38
Starch	8·5	—
Ammonium oxalate	9·5	8

Cambrite is another explosive of this type.

Potassium perchlorate explosives and many ammonium nitrate explosives also contain nitroglycerine.

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CHAPTER V

MILITARY HIGH EXPLOSIVES

ALTHOUGH dynamite and other commercial high explosives are used sometimes for military demolitions and engineering works, the characteristic military high explosive is one that is decidedly insensitive. For filling shell it is necessary to have an explosive that will stand the shock of discharge of the projectile without exploding. For naval mines and many other naval and military purposes an explosive is required which will not go off prematurely when struck by an enemy bullet or shell fragment.

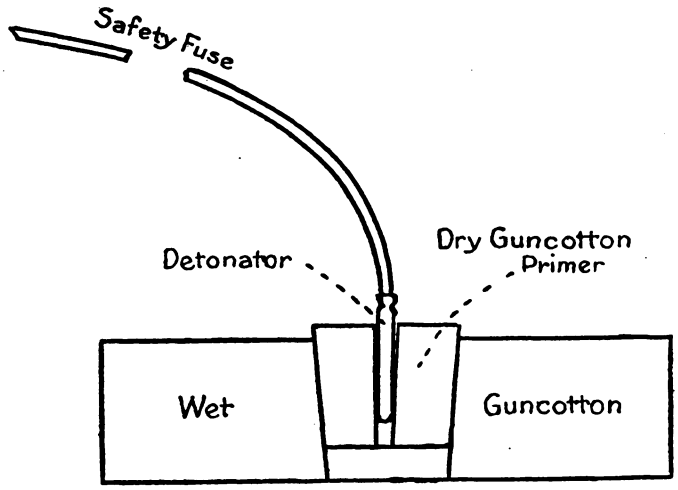

FIG. 8. Guncotton Slab, Primer, etc.

For demolitions slabs of compressed guncotton are used in the British Service. As already stated in Chapter II the slab is fired by means of a primer of dry compressed guncotton, which in turn is fired by means of a detonator. Shell filled with guncotton have also been tried, but they gave rise to premature explosions in the gun and were consequently given up. The principal military high explosives consist largely or entirely of the nitro-derivatives of aromatic compounds.

The principal source of these aromatic compounds is coal tar. When coal is heated it is split up into three classes of products: solid, liquid and gaseous. The last named constitute coal gas; the solid product is coke. The liquid products are very complex; they separate naturally into two

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layers, an aqueous layer containing ammonia and known as ammonia liquor, and a thick black oily liquid called coal tar, which is the principal source of the raw materials from which dyes, synthetic scents, many photographic chemicals, etc., are made, as well as high explosives. There are two sorts of coal tar : gas tar, which is obtained from gas works where the main object is to obtain coal gas, and coke oven tar obtained from installations where coal is heated in order to obtain coke for metallurgical purposes. Until comparatively recently the by-products from the latter source were not generally recovered. The tars from these two sources are very similar.

After allowing the ammoniacal liquor to separate as far as possible the tar is distilled and the distillate is collected in four or five fractions. The residue remaining in the still consists of pitch. The earlier fractions of the distillate are distilled again to separate the products more completely, and these are purified by washing them with acid and alkali and are again submitted to distillation, whereby they are eventually resolved into fairly pure substances or comparatively simple mixtures. The two principal products in the first fraction are benzene and toluene, which form the starting points for the manufacture of numerous substances, including explosives. The alkaline washings of these and of the middle fractions yield on treatment with carbonic acid a number of acid bodies known generically as carbolic acid, which on further purification is separated into phenol and other similar substances. From the medium and heavy oils naphthalene is also obtained. This is a solid hydrocarbon which is also used for the manufacture of various synthetic chemicals, but only to a limited extent for explosives. The heavier fractions from the tar contain anthracene and many other substances which are not usually separated. This oily fraction is used for impregnating wood, etc.

The following are the principal constituents of coal tar that are of importance for the manufacture of explosives :

Benzene	C_6H_6	
Toluene	C_7H_8	or $C_6H_5.CH_3$
Xylene	C_8H_{19}	or $C_6H_5.(CH_3)_2$
Carbolic acid or phenol	C_6H_6O	or $C_6H_5.OH$
Cresol	C_7H_8O	or $C_6H_4.CH_3.OH$
Naphthalene	$C_{10}H_8$	

Benzene and toluene are also present in coal and coke oven gas in the state of vapour and can be recovered by washing the gas with heavy oil, from which they can afterwards be recovered by distillation. From coal gas, however, these substances must not be removed entirely, because the luminosity of the gas is thereby very much reduced. In both the tar and the gas there is more benzene present than toluene, but there is more demand for the latter. The

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benzene can therefore be left in or returned to the gas, whilst the toluene is taken for conversion into trinitrotoluene and other products.

Benzene and toluene are present in the petroleum found in some parts of the world, and products rich in these substances can be obtained from it by suitable treatment. They are also formed in "cracking" or heating heavy mineral oils under the proper conditions of temperature and pressure. The demand for phenol is in war time greater than the supply, but additional quantities can be made from benzene. This is first converted into benzene sulphonic acid by heating it with sulphuric acid. The sulphonic acid is then fused with caustic soda and the resultant product is heated with acid which liberates the phenol.

Phenol on treatment with mixed acid is readily converted into picric acid:

$$\underset{\text{Phenol}}{C_6H_5.OH} + 3\,\underset{\text{Nitric acid}}{HNO_3} = \underset{\text{Picric acid}}{HO.C_6H_2(NO_2)_3} + 3\,\underset{\text{Water}}{H_2O}$$

In practice the phenol is first dissolved in sulphuric acid and to the solution is added a mixture of equal parts of sulphuric acid and nitric acid of 62 per cent. strength. Or the solution is run into a mixture of Chili saltpetre and weak nitric acid.

When the nitration is complete water is added to diminish the solubility of the picric acid, which separates in crystals and is removed and washed with water to free it from the waste acid.

Picric acid is a bright yellow crystalline substance which melts at 122·5° C. and has a density of about 1·7. Formerly it was used as a dye; now it is not itself employed much for this purpose, but it is an intermediate product in the manufacture of some more complex dye-stuffs. It was first made by the nitration of phenol by Laurent in 1843, and it was discovered early that it formed with metals compounds (picrates) which are explosive. Sprengel showed in 1871 that picric acid could itself be detonated, but it was not used for this purpose until E. Turpin in 1885 pointed out the special advantages it possessed as a filling for shell in consequence of its stability, insensitiveness and the violence of its effects. It was adopted by the French Government under the name of Melinite. At first it was mixed with collodion to reduce its sensitiveness, but later picric acid was generally used by itself, either in compressed blocks or cast directly into the shell. In 1911 the Civil Court in Paris granted Turpin 100,000 francs in compensation for the fact that in the interests of the State he had not been allowed to utilise his invention to his own profit. Until the introduction of melinite, black powder had been the only explosive used successfully for filling shell. The other explosives known at that time had proved to be too sensitive.

Picric acid has also been used by various powers for military demolitions.

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Like guncotton it can be detonated completely even when wholly unconfined, whereas gunpowder and many other explosives, including those that contain ammonium nitrate, must be well tamped or confined, otherwise they do not produce a satisfactory result. Picric acid is therefore eminently suitable for carrying out hasty demolitions. But it suffers under two serious disadvantages: it has an inconveniently high melting point, and it is liable to form compounds with metals, especially lead and iron, which are dangerously sensitive. The high melting point makes it difficult to cast into shell and blocks, as the heating must be carried out under special precautions. Trinitrocresol is made from cresol in the same way as picric acid is from phenol, but it presents the same dangers of the formation of sensitive salts with metals and basic substances.

This has caused the adoption of other nitro-derivatives which are not of an acid character.

Benzene cannot be nitrated beyond the stage of dinitro-benzene $C_6H_4(NO_2)_2$ except by round-about and expensive processes. As this substance is not a very powerful explosive it is not used much for military explosives, but it is a constituent of some commercial explosives.

Toluene on the other hand can be converted into trinitrotoluene $CH_3.C_6H_2(NO_2)_3$ without any great difficulty, and this substance is now used on a very large scale as a filling for shell, bombs and submarine mines. It is also a constituent of many composite explosives. It melts at 81° C. and can therefore readily be melted by means of a steam jacket.

The nitration of toluene is usually carried out in two stages: the toluene is first converted into mono- or dinitrotoluene by treating it with mixed acid. The product is then separated from the waste acid and nitrated further with stronger mixed acid at a higher temperature. Dinitrotoluene is also used as an ingredient of explosives, but not on nearly such a large scale as trinitrotoluene. Trinitrotoluene was made in the laboratory as long ago as 1880 and its manufacture was started in Germany in 1891. Experiments were carried out with it by the German military authorities in the late eighties and early nineties of the last century, and in 1902 they adopted it for filling shell and other purposes. Italy adopted it in 1907 under the name of tritolo and Russia soon after. In the British Service it is known as T.N.T. or trotyl; other names for it are trinol and trilite.

Trinitrotoluene is somewhat less sensitive than picric acid and shows no tendency to form sensitive salts or other compounds under the ordinary conditions of use and storage. On the other hand it is about 5 per cent. less powerful and also rather less violent than picric acid. Its power can be increased by mixing it with a nitrate or other oxygen carrier. Like dinitro-benzene and dinitro-toluene it is somewhat poisonous.

Naphthalene cannot readily be nitrated beyond the stage of trinitro-

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naphthalene. This is not a powerful explosive by itself and is only used in conjunction with nitrates or other oxygen carriers.

An explosive which is much used now for filling shell is amatol, which is a mixture of trotyl and ammonium nitrate.[1] The proportions of the two constituents are shown by means of a fraction placed after the name, thus amatol 40/60 is a mixture of 40 per cent. ammonium nitrate and 60 per cent. trotyl, and amatol 80/20 is a mixture of 80 per cent. ammonium nitrate and 20 per cent. trotyl.

An explosive which has been used much for hand grenades is ammonal, which the Austrians have also employed in shell. This is a mixture of ammonium nitrate, aluminium powder and organic and carbonaceous matter, usually trotyl and charcoal; *e.g.*:

Ammonium nitrate	58·6
Aluminium	21·0
Trotyl	18·0
Charcoal	2·4

Ammonium nitrate is itself an explosive, but can only be detonated with extreme difficulty unless it be mixed with oxidisable matter. The mixtures made with it are not very sensitive; hence their use for military purposes. It has the disadvantage that it is very hygroscopic. Therefore these explosives must not be left exposed to the air, or they will absorb moisture and become damp and useless. Compressed blocks are protected by being covered with paraffin wax or other waterproof material, and shell and bombs filled with these mixtures must be thoroughly sealed. In time of war there is not likely to be any serious trouble from this cause as the munitions are expended before there is time for them to suffer deterioration by the absorption of moisture.

Ammonium nitrate is made by neutralising ammonia with dilute nitric acid and evaporating down the solution thus obtained. Until recently practically the sole source of ammonia was the ammonia liquor obtained in the distillation of coal. Now, however, large quantities are made from the nitrogen of the air. In the Haber process nitrogen and hydrogen gases are passed together under very high pressure over a heated contact substance. The gases are then cooled to $-60°$ or $-70°$ C. to cause the ammonia to separate as a liquid. Great difficulties were experienced at first in dealing with large volumes of gas at high temperatures and pressures, but it is said that these difficulties have been overcome in Germany.

In the cyanamide process calcium carbide is heated in a furnace and nitrogen is passed in:

[1] See Official communiqué in *British Medical Journal*, December 12, 1916.

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$$Ca\,C_2 + N_2 = Ca\,N_2\,C + C$$

Carbide Nitrogen Calcium cyanamide Graphite

For the conversion of the cyanamide into ammonia it is treated in a closed tank with steam under pressure in the presence of water and alkali.

$$Ca\,N_2\,C + 3\,H_2\,O = Ca\,C\,O_3 + 2\,N\,H_3$$

Cyanamide Water Calcium carbonate Ammonia

These processes, especially the cyanamide process, have greatly increased the available supplies of ammonia and, by reducing the price, are likely to lead to an increase in the use of ammonium nitrate explosives, which is already very extensive. Ammonia can be converted into nitric acid by Ostwald's process, which consists in passing it rapidly, together with air, over a contact substance such as platinum sponge. It is therefore possible to make ammonium nitrate from water and the constituents of the atmosphere.

High explosive shell then are filled with these mixtures, or with pure nitro-bodies as highly nitrated as possible. Trinitrotoluene (trotyl, T.N.T.) and picric acid (lyddite, melinite) are those most used, but there are others which are employed on a smaller scale, such as nitroxylenes, nitronapthalenes, hexanitrodiphenylamine and trinitro-anisole.

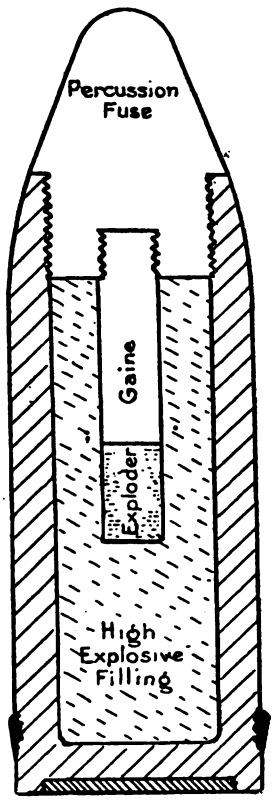

Fig. 9. High Explosive Shell for Field Gun

For the attack of warships shell are required that will pass through the armour and explode when they are on the other side. By providing the shell with a cap of soft iron to protect its nose, and by suitable construction, the mechanical difficulties of obtaining a projectile, which can perform this feat without breaking up, have been overcome to a great extent. It is necessary also that the explosive shall be so insensitive that it will not be exploded by the tremendous shock caused by the impact of the shell on the armour at a velocity of perhaps two thousand feet per second. Black powder fulfils this condition, and until recently armour-piercing shell were generally filled with it, but ammonium nitrate explosives are said to be sufficiently insensitive. Fig. 10 shows an American armour-piercing shell with base fuse, cap, and a false point to make the shell more pointed and consequently reduce the resistance of the air. Fig. 11 shows a similar shell after proof.

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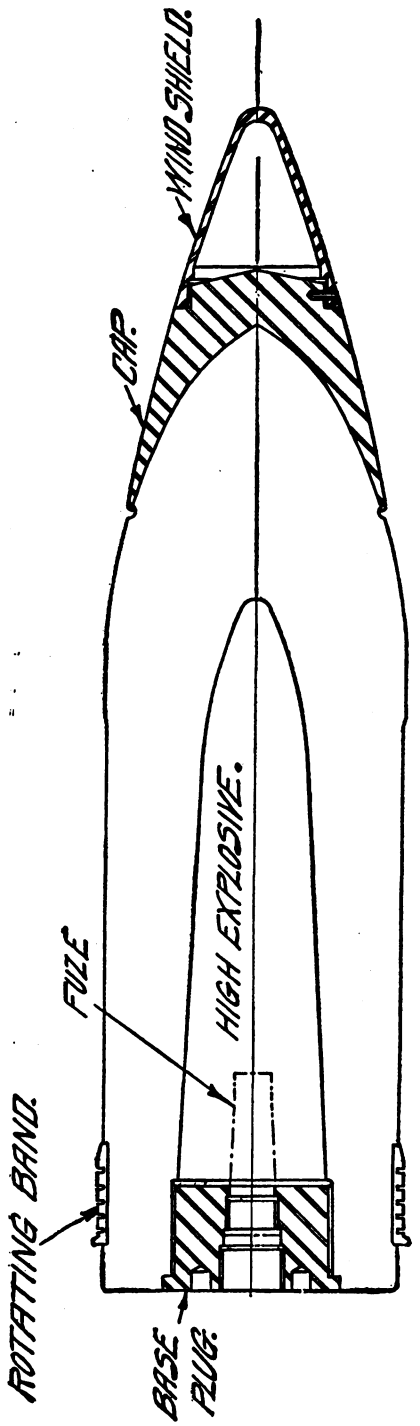

FIG. 10. American Armour-Piercing Shell
(From paper by Maj. E. P. O'Hern in *Smithsonian Report*, 1914, p. 260)

In the construction of shell and their fuses great care must be exercised to prevent premature explosions. In the case of shell charged with gunpowder a premature explosion is dangerous to friendly troops stationed in front of the gun. The detonation of a high explosive shell in the bore, on the other hand, invariably destroys the gun and may kill the detachment as well as other friendly troops. Hence the necessity for making the walls and base of the shell of metal that is above suspicion and of sufficient strength, and of providing the fuses with safety arrangements. Howitzer shell are fired with small charges of powder at comparatively low velocities: therefore the shock of discharge is less and the walls of the shell can be made thinner, and the charge of high explosive greater in comparison.

The weight of bursting charge forms 5 to 25 per cent. of the total weight of the shell. The German howitzers are provided with two sorts of high explosive shell: common high explosive shell and mine shell. The common shell is used against an enemy under cover, who are struck by the fragments of the walls, which mostly fly off at right angles to the axis of the shell when the charge detonates. The walls of these shell are thick. Those of the mine shell are made as thin as possible without incurring the risk of the shell breaking up in the bore of the gun. The charge of high explosive in the mine shell is as great as

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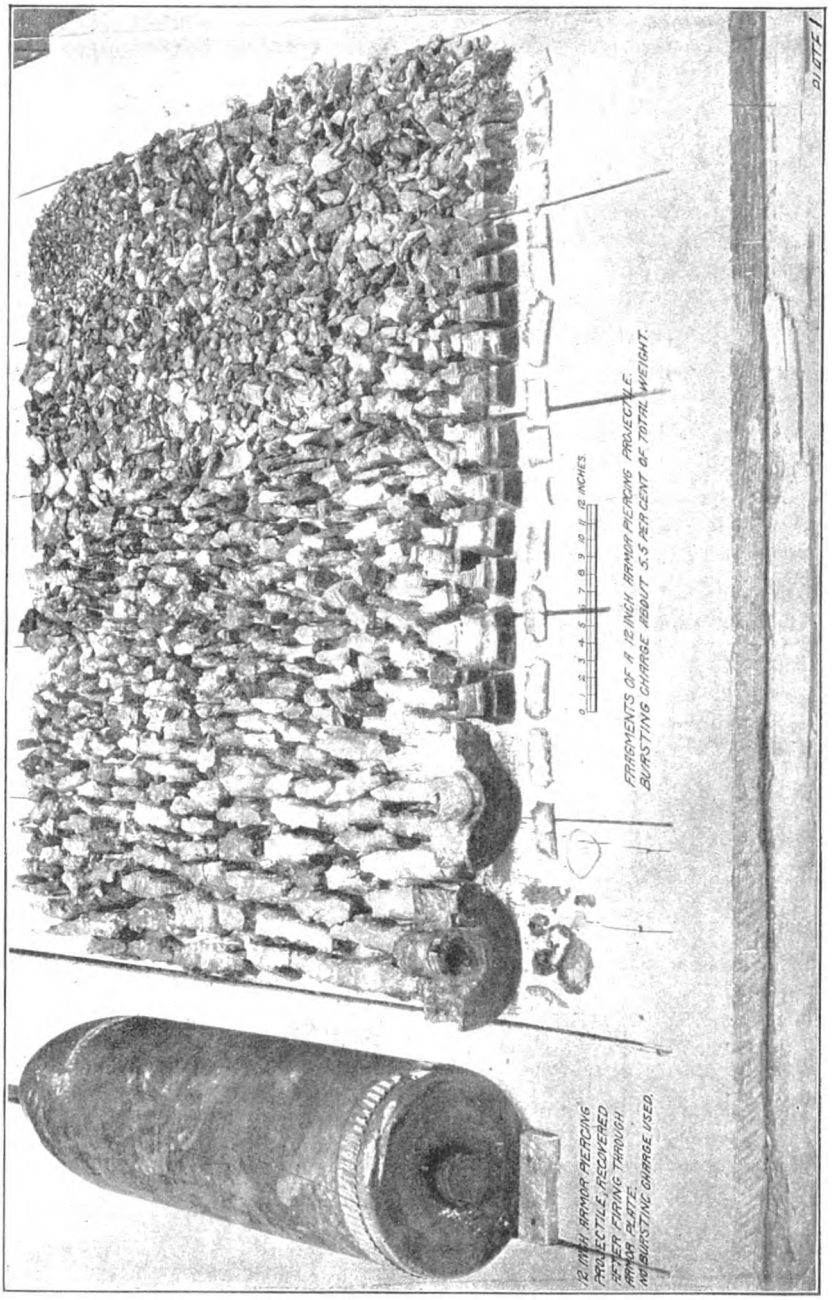

FIG. 11. Armour-Piercing Shell after Proof
(From paper by Maj. E. P. O'Hern in *Smithsonian Report*, 1914, p. 250)

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possible, and the shell are used for the destruction of material obstacles, such as fortifications. The shell are provided with impact fuses. The Krupp 10·5 centimetre (4-inch) howitzer, for instance, fires shell weighing 14 kilogrammes; of these the common shell has a charge of 1·4 kg. and the mine shell of 2·8 kg. The impact fuse of the mine shell is provided with a delay arrangement so that it does not detonate until a few hundredths of a second after striking, and has time to bury itself.

Gunpowder is practically obsolete as an explosive for filling cannon shell as the effects it produces are very inferior. It is, however, still used for opening various sorts of shell which do not depend for their effect upon the explosion of the charge, such as Shrapnel shell. This variety of shell was invented by Lieutenant Shrapnel, R.A., about 1784 and was adopted officially in England in 1803. It consisted originally of a spherical shell containing only a small charge of gunpowder, only just enough to break up the shell. This charge was ignited by means of a time fuse whilst the shell was still in the air, and the fragments consequently travelled on with the original velocity of the shell. They were more effective against troops in the open than solid shot or shell that only burst after they had reached the ground. After the introduction of rifled guns the shrapnel shell was modified. It now consists of a thin cylindrical shell-body with a pointed head surmounted by a time and percussion fuse. The greater part of the shell is filled with bullets embedded in rosin, but in the base there is a chamber containing a small charge of gunpowder, and this is connected with the time and percussion fuse in the nose by means of a channel filled with gunpowder pellets. The charge chamber is separated from the bullets by a stout steel diaphragm. According to the setting of the time fuse the charge explodes at a known time from the discharge from the gun. The pressure generated by the powder bursts off the nose of the shell, and the bullets are driven out of the shell casing in a cone of 15° to 30°. Consequently, if the burst has been well timed, the bullets will sweep over a considerable area. These shell are very effective against troops in the open, but under modern conditions infantry entrenches whenever possible, and artillery is provided with shields and generally fires from concealed positions. Consequently shrapnel has lost much of the importance that was assigned to it, and has been replaced by high explosive shell to a great extent.

In order to avoid the complications caused by providing batteries with two sorts of shell, shrapnel and high explosive, which, moreover, do not range equally, universal shell have been introduced, which can be used for both purposes. In the Ehrhardt universal shell the high explosive charge is in the head. When exploded by the shrapnel time fuse the head flies on in front of the bullets, and when it strikes an object it is detonated by the impact portion of the fuse. If the shell reaches its billet before the time fuse has

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functioned, the impact fuse acts and detonates the trotyl, which scatters all the components of the shell. In the Balkan War it was found that the heads of the universal shell were liable to burst in the air when the shrapnel charge of gunpowder was set off by the time fuse. The makers therefore added a small bursting charge between the bullets and the head so as to blow the head off before the main burster has time to act.

In the Krupp high explosive shrapnel (Fig. 12) the bullets are embedded in trotyl instead of rosin or sulphur. Space is thus saved. When the charge in the chamber in the base explodes it drives out the bullets in a cone together with the trotyl which is partly burnt. But by setting the fuse in a different way, the trotyl can be made to detonate. The charge in the base is said to consist of an explosive which will also detonate under the influence of the trotyl, although when merely ignited it only explodes. The fuses of these shell are necessarily somewhat complicated, but advantage is generally taken of the fact that the shrapnel effect is mostly required with a time fuse, and the high explosive on impact. Such shell are very expensive compared with common high explosive shell or even with ordinary shrapnel, and as the number of shell required in warfare is now so enormous, their use is restricted. However, in consequence of the many purposes for which the weapon is used, the German light field howitzer of 10·5 cm. calibre is provided with a universal shell, which according to the adjustment of the fuse can be used either as shrapnel, as common shell without delay for attacking troops under light cover, and with delay as mine shell for the destruction of strong works. The German 7·7 cm. field gun also fires high explosive shrapnel sometimes.

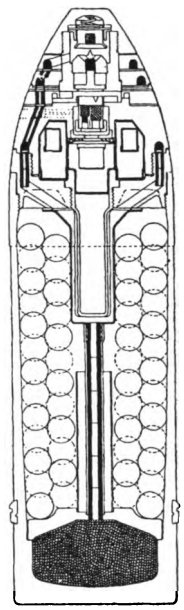

FIG. 12. Krupp Universal Shell

Trench warfare has led to the use of numerous appliances which had before received little attention. Amongst these is to be numbered the trench howitzer, which from a trench or other concealed position throws a shell of considerable calibre with a comparatively low velocity.

In some types of trench mortars the shell are of considerably greater diameter than the gun, and have a stick which goes down the bore. Such shell often have spiral wings fixed to their bases to keep the shell nose first during flight and give it a rotary motion. These are sometimes called aerial torpedoes. Other shells have, fixed to their bases, tubes which fit over an adjustable bar on the gun. The propulsive charge is placed in the tube between its base and the end of the bar. When this is fired it causes the tube and the shell fixed to it to travel in the desired direction. As the shock

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of discharge of a trench mortar is comparatively slight the shell do not require to be constructed so strongly as those for ordinary guns and howitzers. Somewhat more sensitive explosives can be used; the Germans use sometimes explosives of the Astralite type containing a little nitroglycerine.

Trench mortars are often used to assist in breaking the enemy's wire entanglements. For this purpose it would appear advisable to use shell with fairly thick walls as the wire is cut principally by flying fragments, and not to any great extent by the direct blast of the explosion. Ordinary shrapnel shell and high explosive shell are used for the same purpose. Proposals have also been made to clear a passage through a wire entanglement by pushing through it a tube charged with high explosive and then firing it. The tubes are made for convenience in sections which are joined together on the spot.

The use of poisonous gases and vapours by the Germans has rendered it necessary for the opposing Powers to adopt similar measures. Chemicals of various sorts are therefore fired in shell, as well as being released from pipes and cylinders. Such shell have a small opening charge of a mild explosive, such as gunpowder, fired by means of a fuse in much the same way as shrapnel.

For illuminating the country at night, and also for signalling purposes, shell are made similar to shrapnel, but with stars of firework composition instead of bullets. There are from two to twelve stars packed in carefully to prevent damage by the shock of discharge. They are generally filled with a light-giving composition similar to the flash-light powders used in photography, namely, mixtures of magnesium or aluminium powder, or both, with potassium nitrate or perchlorate or barium nitrate, with or without some binding material. In some of the more recent star-shell each is fitted with a parachute which opens when the shell bursts and prevents the star falling too rapidly. Star-shell are provided with time fuses; when the fuse has burnt the proper time it ignites the priming of the stars and also the bursting charge in the base of the shell.

It is often desirable to be able to observe the course of a shell through the air. This is specially the case when attacking airships. For this purpose J. B. Semple devised "tracers," which are fitted into or on to the base of the shell. For use by day the tracer is filled with a dark coloured liquid, which is ejected during flight as a fine spray. The night tracer is filled with a firework mixture, which is ignited as the shell leaves the gun, and renders the course of the projectile visible like that of a rocket.

The hand-grenade, which was introduced in the seventeenth century, and was used very largely during the wars of the eighteenth, lost its importance in the time of the Napoleonic wars, but its use did not cease entirely, for it was employed in 1808–1809 at Saragossa, in 1832 at Antwerp, in 1854–1856 at Sebastopol, and in 1884–1886 by the English in the Sudan. During

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the Russo-Japanese War (1904–1905) the hand-grenade regained much of its old importance, and in the present trench warfare they are used in immense numbers.

The hand-grenade of the eighteenth century was a hollow iron ball about 2½ inches in diameter containing a charge of gunpowder. It had a fuse of slow match which ignited the powder a few seconds after it had been lit and thrown. In 1882 the French adopted a spherical grenade 8·12 cm. in diameter (3·2 inches) with walls 9 mm. (0·35 inch) thick, and containing a charge of 110 grammes (4 oz.) of black powder. It weighed 1·2 kg. (2·64 lbs.). The ignition mechanism consisted of a friction pellet, through which passed a wire with a loop at the other end. The thrower passed through this a hook which was attached by means of a cord to a band round his arm. A wooden fuse contained some slow burning composition which prevented the grenade exploding until several seconds after the friction pellet was ignited by the withdrawal of the wire in the act of throwing the bomb. Towards the end of the nineteenth century the Russians introduced a similar hand-grenade. Grenades of this pattern are in use now, except that the charge consists of high explosives instead of gunpowder. As a hand-grenade does not have to withstand the shock of discharge from a gun, many patterns can be used which would be impossible in the case of shell. Both in the Russo-Japanese War and in the present conflict various patterns of improvised bombs have been used. These are often made of jam tins, artillery cartridge cases or empty shrapnel shell filled with explosive, with the addition of nails or odd bits of iron to act as missiles. Another type is that of the "hair-brush." This consists of a piece of wood, shaped like the back of a hair-brush, on which is laid a slab of guncotton or other high explosive, and on that again some long nails, the whole being bound together by means of wire. Such bombs as these, containing comparatively large charges of explosive, produce considerable moral effect, but are not so deadly as grenades with strong iron or steel walls enclosing smaller charges.

The grenades that are not improvised, but manufactured in a regular way, conform generally to two different types: one is the "cricket ball" or "egg" type, resembling the old grenade or that shown in Fig. 14. The other is a cylindrical or oval bomb attached to a handle to facilitate throwing it. This type is often known as the "Policeman's truncheon." The Hale hand-grenade is of this class. In the early patterns the explosive was contained in a brass tube, round one end of which was a ring of iron or lead with grooves in it to make it split into segments. But in later patterns the container itself is of stout cast steel and there is no ring. Fig. 13 shows a grenade of this type which was devised by Captain Lischin in 1904 and used by the Russians in the battle of Mukden. It was charged with dry guncotton "*C*" and a 1 gramme detonator. The cap *D* could be turned so as to make the

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grenade either live or safe. As a further precaution the cap *K* was kept on until the grenade was used. In more recent bombs of this type the second cap is done away with, and for it is substituted a safety pin which is withdrawn just before throwing. Also trotyl or other high explosive is used instead of guncotton, and there is an exploder between the detonator and the charge. On impact the pin *O* is driven into the detonator and fires it. The wooden handle *B* is about 18 inches long and often has attached to it a tail of some fabric to cause the grenade to travel nose first.

The fuses of hand-grenades may be made to act either by time or percussion. A time fuse is usually arranged to fire the grenade in about five seconds, which gives sufficient time for throwing the grenade, but not enough for the enemy to throw it back. The disadvantage of the time fuse is that, if for any reason the bomb be not thrown almost at once, it may be fatal to the thrower and his companions. There are reports of soldiers who have caught grenades against the edge of their own trenches so that they fell back at their feet. By placing themselves on the grenades they have sacrificed their lives to save their fellows.

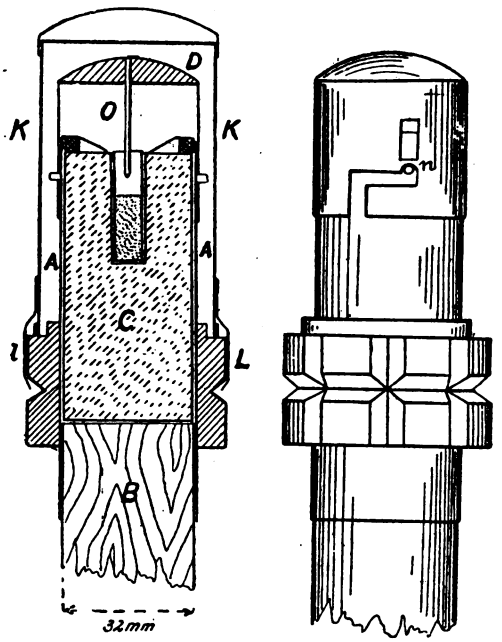

FIG. 13. Lischin's Hand-Grenade
(From *S.S.*, 1911, p. 433)

The methods of lighting the time fuses are various. One of them has been described above. Another is to provide the end of the fuse with a match head, which is rubbed on a prepared surface just before the bomb is thrown. Or the fuse may be started by removing a safety disc and striking the head of the grenade against an obstacle. Others again are started automatically by the act of throwing the bomb.

In the Mills hand-grenade (Fig. 14) the time fuse is started by releasing the lever or trigger in the act of throwing. There is also a safety pin which is removed just before use. When the trigger is released the spring causes the striker to impinge on the cap, which ignites a length of 2 inches of fuse, and this after about five seconds fires the detonator, which detonates the charge.

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The impact fuse also suffers under disadvantages. It is not easy to make sure that the grenade will always fall on its nose, although the grenade is often provided with a tail consisting of strips of cloth or similar material, and it is difficult to make a fuse that will act if the missile falls on its side or base. Moreover, there is always danger that the thrower may hit the grenade against the walls of the trench and kill himself and his fellow soldiers. All grenades must be provided with some safety device which is removed by the thrower just before he throws it. But many also have a further ingenious mechanism of some kind which prevents the grenade becoming active until it has travelled some little distance. One of the difficulties lies in the fact that grenades are often required to act at very short range, as when they are just dropped over a traverse in a line of trenches. The modern hand-grenade has not yet been in use long enough for finality to be reached in the designs.

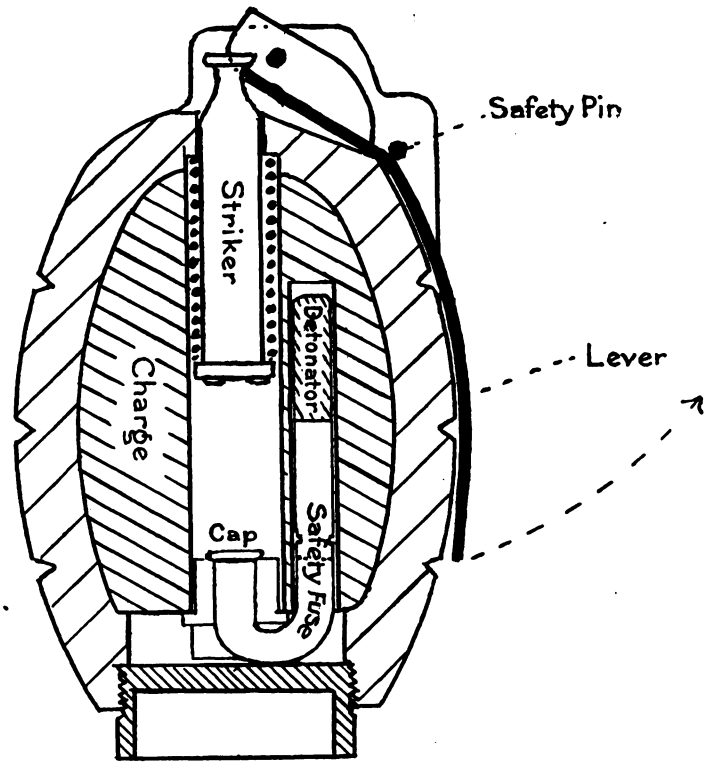

FIG. 14. Mills Hand-grenade

For filling hand-grenades almost any high explosive could be used, but the more insensitive it is the safer it is under the very severe conditions of active service. The explosives actually utilised are much the same as those used for artillery shell. Cheddite and ammonal are also used.

Grenades are also made to throw with a sling or catapult, and there are rifle-grenades, such as that of Hale, which can be fired from a rifle to a distance of a few hundred yards. The rifle-grenade has a rod which goes down the barrel of the rifle, and it is fired with a special cartridge having no bullet. A safety pin is removed before firing, but the grenade does not become live

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until it has travelled some distance and some vanes attached to it have, by rotating, released the striker, which on impact hits the detonator.

In the case of bombs to throw from flying machines there is not the same limitation as to weight. The principal difficulty here is to attain a sufficient precision without approaching the enemy so close as to place the aviators in great danger. Some ingenious appliances have been designed for sighting the dropping mechanism, but the accuracy is much lower than that of a gun. As an aeroplane can only carry a few bombs it is necessary to employ a considerable number of aeroplanes to carry out a bombardment. Aeroplane bombs are fitted with a safety arrangement which only allows the detonating mechanism to come into action after the bomb has fallen a considerable distance. This may take the form of a set of vanes rotated by the air until it releases a striker, which on impact strikes the detonator.

For the attack of flying machines special guns are made of extra high muzzle velocity and high angle fire. For the destruction of Zeppelins and other dirigibles endeavours are made to set light to the hydrogen of the balloons, but this is not so easy as it seems, because the projectile passes through the envelope so rapidly that it has little time to ignite the gas at the spots where it enters and leaves.

Flying machines are frequently provided with incendiary bombs for the destruction of property. These may be charged with inflammable substances such as petrol, tow steeped in tar, or celluloid, together with some match composition which ignites on impact or at a fixed time after the bomb has been dropped. Another substance used for incendiary bombs is thermit, a mixture of iron oxide and aluminium or other similar materials. On strong ignition a chemical reaction sets in with a large evolution of heat, producing a white hot molten mass of metal and slag. A small charge of explosive is also added sometimes to scatter the incendiary materials. Incendiary shell are also made containing thermit and other incendiary matter and a small charge of a mild explosive such as gunpowder, to open the shell.

For hasty demolitions the explosive must be of such a nature that it can be detonated unconfined, but yet it must not be sensitive to shocks or friction. It should not be exploded by the impact of a bullet. Compressed blocks of wet guncotton, picric acid or trotyl are used. Dynamite, blasting gelatine and some other commercial explosives can also be employed, but under the conditions of active service they are considerably more dangerous. With any explosives the charge should be well tamped, if possible, as the effectiveness of the explosive is greatly increased thereby. Ammonium nitrate explosives and other insensitive commercial explosives are not suitable for hasty demolitions, as they are not completely detonated unless well confined. Smokeless powder is also used sometimes for demolitions, but is difficult to

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detonate, especially the larger sizes. Ballistite is employed in Italy for this purpose.

For military mines the explosives used must depend largely on the nature of the ground or rock. In soft rock or earth gunpowder could be used, but a great weight is required to produce the same effect as a smaller quantity of many other explosives. It also has the disadvantage that on explosion it gives a considerable quantity of carbon monoxide which is a poisonous gas. Ammonal has been much used in Flanders: if it contain a sufficient proportion of ammonium nitrate it gives rise to no noxious fumes.

For submarine mines and torpedo war-heads the requirements are much the same as for military blasting. As long ago as the Crimean War (1854–1856) Emanuel Nobel, the father of Alfred Nobel, is said to have devised mines charged with guncotton to protect the mouth of the Neva. Mines were also used in the American War of Secession (1861–1865). They are now generally charged with trotyl and are provided with ingenious devices to cause them to lie in the water at the required depth and to be exploded when a ship strikes the mine or a connecting cable.

The name, torpedo, is borrowed from an electric fish and was applied at one time to submarine mines of all kinds. Now its use is restricted to mines provided with means of propulsion. The modern torpedo is driven by an engine actuated by compressed air which is heated by means of a burner so as to increase the power. It is provided with a gyroscope to keep the direction constant, and is launched from a tube by a charge of smokeless powder. It travels with a speed of thirty to forty-five knots, and has a range of 10,000 to 11,000 yards (6 miles). In the head there is a charge of about 200 lbs. of high explosive, usually trotyl. On reaching its objective a pistol mechanism in the nose of the torpedo fires and causes the charge to detonate.

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CHAPTER VI

COMMERCIAL HIGH EXPLOSIVES

In addition to the nitroglycerine explosives mentioned in Chapter IV there are many other mixtures used in mines, quarries and engineering works. A very important class is that of the ammonium nitrate explosives, which are comparatively safe to handle and are not expensive to manufacture. Attention was first drawn prominently to the use of ammonium nitrate as a constituent of explosives in consequence of the numerous explosions of coal damp and dust in mines. The comparatively small amount of heat that is liberated in the explosion of mixtures containing large proportions of ammonium nitrate indicated their use for this purpose, but they are also being used more and more for general blasting work.

In 1867 the Swedish chemists Ohlsson and Norrbin took out a patent for explosives consisting of ammonium nitrate mixed with such substances as charcoal, saw-dust, naphthalene, picric acid, nitroglycerine and nitrobenzene. Until the introduction of the fulminate detonator, however, they could not be exploded satisfactorily. In the seventies Alfred Nobel took up these explosives, but after he had invented blasting gelatine he ceased for some time to take much interest in ammonium nitrate explosives. In 1884 and 1885 Favier took out patents for mixtures of ammonium nitrate with nitro-naphthalene, paraffin and resin. Their manufacture was soon afterwards undertaken by the French Government and is still continued under the names of Explosifs N, or Explosifs Favier or Grisounites.

In the manufacture of these explosives the ammonium nitrate is dried and ground in a mill, the pan of which is heated by steam or hot water. The nitronaphthalene is then added and the ingredients are incorporated together for an hour or two. The mixture is allowed to cool and is ground to a powder, which is then loaded into cartridges. In some cases the cartridges are formed under considerable pressure, but it is then necessary to make them with hollow cores which are filled with primers of the powdered explosive, because if the density be too high the explosive is very difficult to detonate. In other cases the cartridges are formed under a moderate pressure only, such as that

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produced by an archimedean screw working against a slight resistance. The cartridges are contained in wrappers of metal foil or paper waterproofed by dipping them in paraffin wax. Waterproofing is absolutely necessary because ammonium nitrate is extremely hygroscopic.

The following are the compositions of grisounites made by the French Government:

	Grisou-Naphthalite couche		Grisou-Naphthalite roche		For mines free from fire damp, etc.
	N_1a	N_4	N_1b	—	N_1c
Ammonium nitrate . . .	95	90	91·5	86·5	87·4
Potassium nitrate . . .	—	5	—	5	—
Dinitro-naphthalene . . .	—	—	8·5	8·5	12·6
Trinitro-naphthalene. . .	5	5	—	—	—

The grisounites-couches are used in the coal seams; the grisounites-roches, which are more powerful and give higher temperatures, are used in the rocks. The addition of 5 per cent. of potassium nitrate has been found to make the explosives safer.

The following explosives, amongst others, were formerly permitted for use in British coal mines:

	Ammonite	Bellite		Roburite
		No. 1	No. 3	No. 3
Ammonium nitrate . . .	88	83·5	93·5	88
Dinitro-naphthalene . . .	12	—	—	—
Dinitro-benzene . . .	—	16·5	6·5	11
Chloro-naphthalene . . .	—	—	—	1

A few years ago a more severe test was introduced in England for coal mine explosives and it was found necessary to dilute these explosives with 20 to 27 per cent. of sodium chloride or ammonium chloride to enable them to pass it. Trinitrotoluene has in some cases been substituted for other nitro-bodies.

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	Ammonite No. 1	Bellite		Faversham Powder No. 2	Negro Powder No. 2	Roburite No. 4
		No. 2	No. 4			
Ammonium nitrate .	75	61	66	47·5	57	61
Potassium nitrate .	—	—	—	24	—	—
Trinitrotoluene .	5	—	—	10	15	16
Dinitro-benzene .	—	12	14	—	—	—
Ammonium chloride.	—	—	—	18·5	—	—
Sodium chloride .	20	27	20	—	27·5	23
Graphite . . .	—	—	—	—	0·5	—

Ammonal is used to a considerable extent in quarries. It often contains 80 to 90 per cent. of ammonium nitrate, a few per cent. of charcoal and up to 18 per cent. of aluminium powder. Trinitrotoluene is also often added to this mixture. The oxidation of the aluminium in the explosion greatly increases the amount of heat set free, but does not add to the volume of gas. It gives good results when detonated in a lead block in the Trauzl test, but this may be due rather to the fusion of the lead than to extra power in the explosive. The presence of the aluminium renders the explosive easier to detonate.

Another somewhat similar explosive is sabulite, which contains calcium silicide instead of aluminium.

As mentioned in Chapter IV American ammonia dynamites contain ammonium nitrate in substitution for about half the nitroglycerine. In Europe some ammonium nitrate explosives are made containing a small proportion of nitroglycerine, which renders them easier to detonate. As an example may be taken Monobel :

Nitroglycerine	10
Ammonium nitrate	80
Wood meal	10

This was formerly permitted for use in dangerous coal mines, but it has not passed the more severe Rotherham test. It is used, however, for general blasting purposes. To enable these explosives to pass the Rotherham test it has been found necessary to add a considerable proportion of a cooling agent or diluent, such as ammonium oxalate or sodium chloride.

The French make coal mine explosives of this class under the name of Grisoutines :

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	Couche	Couche au salpêtre	Roche	Roche au salpêtre
Nitroglycerine	12·5	12·0	29	29
Collodion cotton . . .	0·5	0·5	1	1
Ammonium nitrate . . .	87·5	82·5	70	65
Potassium nitrate . . .	—	5·0	—	5

These contain a large excess of oxygen.

Potassium chlorate $KClO_3$ was discovered in 1786 by Count Claude L. Berthollet, at least he first showed how it could be prepared in the pure state and investigated and described its properties. He found that if it be substituted for the saltpetre in gunpowder, a much more powerful and violent explosive is obtained, and an attempt was made to manufacture gunpowder of this sort. It resulted, however, in an explosion which killed two of the party that was watching the experiment. In spite of repeated attempts it has not been found possible to make a satisfactory propellant with chlorate, the explosion is always liable to be too violent and uncontrollable, and even for blasting these explosives are not safe, as they are too sensitive to blows and friction, unless additions are made to render them less dangerous. They are specially dangerous if they contain sulphur or a sulphide in addition to chlorate. Potassium chlorate by itself is an explosive, but in the absence of combustible matter it can only be exploded with great difficulty. It has, however, given rise to several severe accidents.

In 1871 Sprengel took out patents for explosives consisting of an oxidising substance and a combustible which were to be mixed together only just before use. Many different combinations were proposed, but necessarily one of the constituents must be liquid. The only Sprengel explosives that have been used on a large scale consist of porous blocks of potassium chlorate, which are dipped before use into a liquid combustible. The French Government provides an explosive of this sort under the name of "Explosif 0 3" or "Prométhée." The oxygen carrier consists of chlorate mixed with a little manganese dioxide, and the combustible of a mixture of nitro-benzene, turpentine and naphtha. The former when dipped in the latter takes up 8 to 13 per cent. of it. These explosives have never been authorised for use in Britain, but, under the name of Rack-a-rock, they have been much used in America, Siberia and China, the combustibles employed being nitro-benzene and "dead oil," which is a mixture of hydrocarbons obtained from coal tar.

In 1897 it was discovered by E. A. G. Street that the dangerous sensitiveness of chlorate mixtures could be reduced by coating the chlorate with an

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oily material such as castor oil thickened by having a nitro-compound dissolved in it. These explosives are called Cheddites, from Chedde, the place in Haute Savoie, where the chlorate is manufactured by electrolytic methods. The following are the compositions of this class which are most used in France :

	0 2 or Cheddite No. 4	0 5 or Cheddite No. 1
Potassium chlorate	79	—
Sodium chlorate	—	79
Castor oil	5	5
Nitro-naphthalene	1	—
Dinitro-toluene	15	16

A similar explosive is Steelite which consists of potassium chlorate mixed with oxidised resin, made by treating colophony and starch with nitric acid. A little castor oil is added. In Germany this explosive is called Silesia.

The perchlorates possess the advantage over the chlorates that they are more stable and less sensitive, although they contain a larger proportion of oxygen. Consequently it is not necessary to coat the particles of perchlorate with fatty matter. Since the introduction of electrolytic methods of manufacturing them the perchlorates have been used largely for the manufacture of explosives.

An explosive of this class is Permonite, which is a mixture of potassium perchlorate and ammonium nitrate with trinitrotoluene and a little starch and wood meal. A little blasting gelatine is sometimes added to assist detonation.

Nobel Polarite, which is somewhat similar, is an explosive of considerable power, and is used in England as a substitute for gelignite, over which it possesses the advantage that it does not freeze readily.

To render these explosives safe for use in coal mines a considerable proportion of ammonium oxalate is added, which has a cooling effect and consequently prevents the formation of long flames. One of the explosives on the Permitted List is Dynobel which has the composition :

Potassium perchlorate	27
Nitroglycerine	32·5
Collodion cotton	0·7
Ammonium oxalate	29·5
Wood meal	10·3

Neonal, Ajax Powder and Swale Powder are similar to this, but contain small quantities of nitrotoluenes as well.

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Whereas ammonium chlorate is a dangerous substance liable to decompose spontaneously with explosive violence, the corresponding perchlorate is stable and can be used as an ingredient of explosives. A disadvantage of this substance is that on explosion it forms hydrochloric acid which is poisonous, but if a sufficient quantity of sodium or potassium nitrate be added the hydrochloric acid is converted into the corresponding chloride and so rendered innocuous. Blastine, an explosive of this class which is used extensively, is a mixture of ammonium perchlorate and sodium nitrate with dinitrotoluene and paraffin wax. Yonckite, which was made in Belgium, consisted of ammonium perchlorate, ammonium nitrate, sodium nitrate and trinitrotoluene. For use in coal mines a mixture was made containing 20 per cent. sodium chloride.

The principal factors which govern the choice of a blasting explosive for any particular purpose are the power, violence and price. The sensitiveness, stability and the nature of the products formed must also be taken into account in some cases. For blasting very hard rock, such as gold quartz, a very violent (brisant) explosive is required; and on account of the expense of drilling the bore-holes it must give a maximum of power in a minimum of volume. Blasting gelatine possesses all these qualities in a high degree, but if fired with a detonator of only moderate power its velocity of detonation is only about 1,500 metres per second instead of 7,000, and consequently it is not sufficiently violent. To a less extent this applies to other gelatinised explosives, and accounts for the preference given in America and South Africa to non-gelatinised mixtures, which are not looked upon with favour in England on account of the danger of exudation of the nitroglycerine. Gelatinised explosives should as a rule be detonated by means of a priming cartridge of dynamite or other non-gelatinised explosive in which the detonator is embedded.

With softer rocks the cost of drilling is less; the bore-hole can consequently be made larger, and the density and power of the explosive are not so important. In Great Britain gelignite is the explosive most used for this class of work, but ammonium nitrate, chlorate and perchlorate explosives are also much employed. If it be desired not to break up the material too much, a very high velocity of detonation is a disadvantage, and care should be taken not to overcharge the bore-holes. For soft material such as coal, which it is not desired to break up too much, a mild explosive is best. Hence the popularity of Bobbinite. When the condition of the material is unimportant, as in the case of carnallite in the German potash mines, the principal consideration is to obtain the maximum power for the money spent. Sprengsalpeter is therefore much used for this purpose. Its slow rate of explosion is said, moreover, to be of advantage. The explosive should not be more violent than the nature of the rock requires.

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In America it has been found that 60 per cent. gelatine dynamite gives as good results as higher grades or as blasting gelatine unless the rock be extremely hard and tough. For tough granite and hard boulders 60 per cent. straight dynamite is used, for rock of moderate toughness 50 per cent., and for hard earth or sandstone 20 to 30 per cent. Judson powder is used for soft, crumbly or seamy rock, and black powder for soft earth, or in quarries where blocks of considerable size are required. Ammonia dynamites are employed where a heaving effect is desired.

For breaking up iron or steel castings a very brisant explosive is required, as also in all cases where it is impracticable to tamp the charge well. For torpedoing oil wells also a violent explosive such as dynamite is used. For breaking up ice, a mild explosive such as gunpowder should be used if it be desired to obtain the ice in large lumps. If, however, it be required to break a passage through an ice-field, by placing charges on or in the ice, a brisant explosive is required. When the charge can be placed under the ice a mild explosive such as gunpowder or blasting saltpetre is better.

For blasting rock under water a brisant explosive is best, and the cartridges must be thoroughly waterproofed, unless the explosive contains a considerable percentage of gelatinized nitro-glycerine. In cold weather there is great danger of the nitro-glycerine freezing after the cartridges have been placed in the bore-hole under water. Extra strong detonators should therefore be used. Under water an explosive produces considerably less effect upon the rock that it would on land, for the pressure of the surrounding water lends support to the material that is being blasted.

Of late years there has been a great increase in the use of explosives for agricultural purposes: for breaking up hard sub-soil, removing tree-trunks, digging ditches, etc. If the charge can be tamped well, non-detonating explosives, such as blasting powder, would probably be the most economical on account of their low price, and the fact that the cost of the detonator is saved. In many cases, however, the ground offers so little resistance to the gases of explosion that it is better to use a detonating explosive.

Some years ago there was much talk of preventing hailstorms by bombarding the sky with high explosives, the idea being that the shock would cause the moisture to be precipitated as rain instead of hail. Much money was spent on endeavours of this sort in the vine districts of Styria, Italy, and France, and there were loud claims of great success, but later on the enthusiasm waned and died: in fact many of the previous advocates of the shooting came to the conclusion that it actually made the hailstorms worse. Be that as it may, an experimental inquiry carried out on a very large scale on behalf of the Italian Government led to the conclusion that the shooting did absolutely no good. The same applies to the production of rain. Experience

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during the present war shows that even the most intense bombardment has no perceptible effect on the weather.

The price of the raw materials is a very important factor in the decision as to what constituents shall be used in the manufacture of explosives. Only inexpensive substances can compete with those already in use. There must be also sufficient quantities of these materials available. The present War has brought about some changes due to the failure of supplies of certain of the raw materials previously used on a large scale for the manufacture of explosives. In England sodium nitrate has in some cases been substituted for potassium nitrate.[1] In Germany nitrates have become scarce in consequence of the stoppage of the delivery of sodium nitrate from South America. To a great extent this scarcity has been met there by the erection of large plants for the manufacture of nitrates from the air, but the produce of these plants is required for making military explosives, and there has consequently been a great development in the production and use of explosives not containing nitrates or nitro-compounds, or only containing them in small proportions. On March 20, 1915, all the Chili saltpetre in Germany was commandeered at a price of 240 marks per ton, and steps were taken to encourage the production of chlorate and perchlorate explosives.

For the same reason liquid oxygen explosives have received renewed attention in Germany. In 1895 Professor F. C. Linde discovered that mixtures of liquid oxygen and various organic or carbonaceous materials could be detonated, and he gave the explosive thus made the name of Oxyliquit. It possesses several advantages: it is cheap, for liquid oxygen can be produced at a cost of a few pence per kg.; it can be fired with safety fuse without a detonator; and in the case of a miss-fire the charge becomes quite safe in half an hour in consequence of the evaporation of the oxygen. It was tried on a large scale in 1899 in the construction of the Simplon tunnel. The cartridge consists of kieselguhr mixed with petroleum, or of absorbent cork charcoal, in a suitable envelope. Liquefied air rich in oxygen is obtained from a liquefying plant near at hand, and the cartridge is dipped into this before use. The charging, tamping and firing of the charge must be carried out rapidly before too much of the oxygen has evaporated. This is the principal objection to the method, and until recently has prevented its adoption, but the necessities of war have led to its revival, and possibly the extended experience thus gained may lead to its retention in times of peace.

The following table gives the quantities of different explosives that were used in Great Britain and Ireland in coal and metalliferous mines and quarries in 1914:

[1] Annual Report of H.M. Inspectors of Explosives, 1915.

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	Quantity used	Percentage	Use
	lbs.		
Gunpowder	16,051,879	49·5	All purposes
Permitted explosives	8,724,866	26·9	Coal mines
Samsonite	403,015	1·2	,, ,,
Saxonite	129,608	0·4	,, ,,
Ammonal	327,850	1·0	Mostly quarries
Ammonite	108,030	0·3	Mostly coal mines
Rippite	208,331	0·7	,, ,, ,,
Arkite	195,843	0·6	,, ,, ,,
Stowite	123,290	0·4	,, ,, ,,
Swalite	137,622	0·4	,, ,, ,,
Others on old Permitted List	699,841	2·2	,, ,, ,,
Gelignite	3,926,140	12·2	All purposes
Modified gelignites	84,463	0·3	Coal mines and quarries
Gelatine dynamite	390,576	1·2	Metalliferous mines
Blasting gelatine	309,393	0·9	,, ,,
Cheddite	184,525	0·6	Quarries
Nobel Polarite	193,136	0·6	Coal mines and quarries
Blastine	142,521	0·5	Quarries
Blasting Bellite	22,837		,,
Dynamite	12,201		,,
Ergites	10,100		,,
Sabulite	2,329	0·1	Metalliferous mines
Tonite	1,978		Quarries
Oakley Quarry Powder	1,825		,,
Steelite	990		,,
	32,393,184	100·0	

Of the different classes of coal mine explosives on the "Permitted List" the following quantities were used in Great Britain in 1914:

	Thousands of pounds	Percentage
Black powder mixture (Bobbinite)	1144	13·1
Gelignites with cooling agent	54	0·6
Carbonites	309	3·6
Ammonium nitrate explosives containing nitro-aromatic compounds but no nitroglycerine	2825	32·4
Ammonium nitrate explosives containing a little nitro-glycerine	2351	27·0
Potassium perchlorate explosives	2032	23·3
	8715	100·0

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In the United States in 1915 the consumption in millions of pounds was :

	Coal mines	Other mines	Railways and other constructions	All other uses	Totals
Gunpowder	167·5	6·7	7·2	16·3	197·7
High explosives (non-permissible)	22·4	109·1	22·3	82·0	235·8
Permissible explosives . .	21·8	4·7	0·1	0·7	27·3
Totals	211·7	120·5	29·6	99·0	460·8

Some of the products formed by explosives are poisonous, notably carbon monoxide, which is produced in considerable proportion whenever the oxygen in the explosive is insufficient to convert all the carbon into dioxide and the hydrogen into water. The gases from black powder of standard composition contain from 8 to 17 per cent. of carbon monoxide by volume, but if the percentage of saltpetre be less than 75 of course there is more. Blasting gelatine contains just about enough oxygen for complete combustion, and British gelatine dynamites and gelignites usually have a slight excess. Ammonium nitrate explosives often contain a considerable excess of oxygen, but they vary very much in this respect, and some are deficient in this constituent. Many of the explosives used in coal mines give more carbon monoxide than dioxide. As a rule the ventilation is so good that no evil consequences result, but this is not always the case. In the days when black powder only was used, mine sickness was a frequent complaint and was due to poisoning with carbon monoxide. Fatal accidents have occurred through poisoning with this gas in badly ventilated mines, and cases of sickness have been quite frequent. Even when the explosive contains sufficient oxygen to convert all its carbon into the non-poisonous dioxide, there is some monoxide formed from the combustion of the wrappers and the safety fuse.

The highly poisonous character of carbon monoxide is due to the fact that its affinity for the hæmoglobin of the blood is about 250 times that of oxygen. Consequently, when a man works in an atmosphere contaminated with the gas his blood gradually becomes more and more inactive, and it only regains its full power of supporting life many hours after the man has returned to a normal atmosphere. A fraction of a per cent. in the air is enough to produce serious results. It has no smell, but can be detected by taking small birds, such as canaries, into the mine, as these are affected much more rapidly than men and fall from the perch before a human being feels any ill effects. Chemical tests can also be applied. The high explosives used for

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hasty military demolitions, guncotton, picric acid and trinitrotoluene, form large quantities of carbon monoxide when detonated. Hence they are unsuitable for use in underground workings. When properly detonated practically all the nitrogen in an explosive is liberated as such, but when, through faulty ignition or tamping, the explosive burns, oxides of nitrogen are formed and these are decidedly poisonous. The treatment of such cases is dealt with in Chapter XI.

Ammonium perchlorate explosives, such as Blastine, form hydrochloric acid on explosion. This is about ten times as poisonous as carbon monoxide, but probably is not so dangerous as it has a strong smell and consequently cannot escape notice.

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CHAPTER VII

SMOKELESS POWDERS

THE first successful smokeless powder was introduced about 1865 by Major Schultze of the Prussian Artillery. It was made by nitrating purified wood fibre and then mixing it with the nitrates of potassium and barium. This powder was too violent for rifles but proved satisfactory for shot guns, and with modifications is still made and used. In 1882 W. F. Reid and D. Johnson took out a patent for a powder consisting of grains of nitrocotton hardened by treatment with a solvent, ether-alcohol, and mixed with nitrates. This is called E.C. Powder (from Explosives Company) and is still in use for shot-guns.

To obtain a smokeless powder suitable for rifled fire-arms it is necessary to carry the gelatinisation much further, and this step was taken in 1884 by the French engineer Vieille. He made the nitrocotton into a gelatinous paste by incorporating it with ether-alcohol, and then made it into strips and flakes and dried it. This powder is called Poudre B after General Boulanger, who was Minister of War at the time of its introduction. In 1889 a similar powder was introduced in Germany.

In 1888 Nobel invented a powder called Ballistite, consisting of a nitrocotton of low nitration gelatinized with nitroglycerine, and in the same year an English Committee adopted Cordite, a mixture of nitroglycerine, mineral jelly (vaseline) and highly nitrated guncotton gelatinised by means of acetone.

Every nation now uses propellants consisting principally of gelatinised nitrocellulose, with or without the addition of nitroglycerine. These gelatinised powders, when suitably ignited in the gun, burn from the surface inwards: consequently the time of explosion can be increased by making the individual pieces bigger. Without altering the composition, powders can be produced suitable for every sort of rifled fire-arm from a pistol to a 16-inch gun.

The nitrocellulose must first be dried. This may be done in a suitable stove by blowing hot air through, but dry nitrocellulose is dangerous and troublesome to deal with and, if the solvent that is to be used be ether-

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alcohol, the water can be displaced more conveniently by means of alcohol. For this purpose the nitrocellulose is packed into cylinders and strong alcohol is injected at the top; water escapes from the bottom and then weak alcohol, which is strengthened up again for use. Finally fairly strong alcohol comes through which is used for the preliminary alcoholising of a further charge.

Poudre B is made from a mixture of two nitrocottons: one, CP_1, is a guncotton containing about 13 per cent. of nitrcgen and only about 10 per cent. of matter soluble in ether-alcohol; the other, CP_2, contains 12 to 12·5

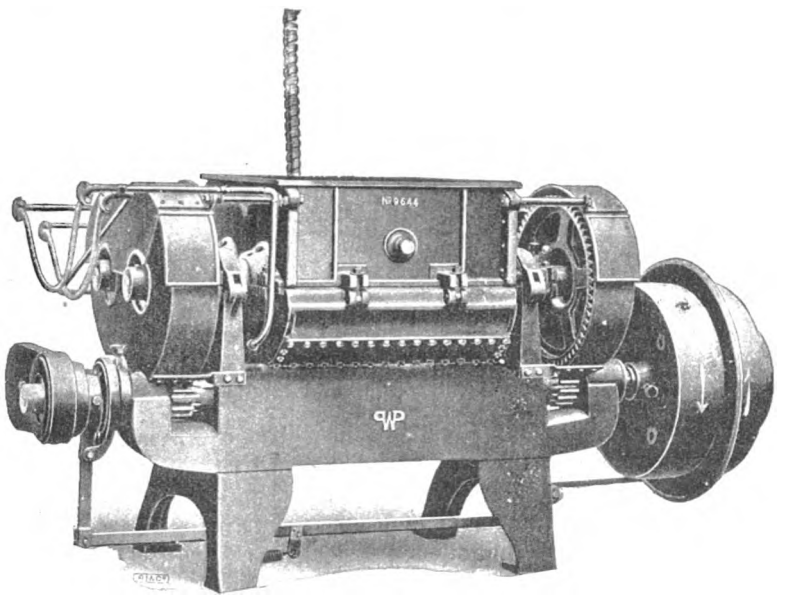

Fig. 15. Incorporating Machine in Working Position
(Werner, Pfleiderer and Perkins, Ltd.)

per cent. nitrogen and is almost entirely scluble in ether-alcohol. These are mixed in various proportions according to the size of powder to be made; rifle powders contain 20 to 25 per cent. of CP_2, the largest powders 50 to 55 per cent. The mixture is dehydrated with alcohol and then placed in an incorporating machine (Figs. 15, 16), ether and more alcohol are added, containing a small proportion of diphenylamine, which is added to increase the stability of the powder. The incorporating machine is then started. The two axles rotate at different speeds, and the blades knead the dough-like mass until it becomes uniform. The incorporation lasts one to three hours and then the dough is placed in air-tight boxes to "ripen." By means of

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a press it is now squirted through a die which forms it into a strip. The strips are freed from solvent, first by drying with air, then by immersion in warm water and then with hot air again. The amount of volatile matter is thus reduced to 0·8 to 2 per cent. according to the size of the powder.

The powders are given letters according to the purpose for which they are intended: thus B.F. and B.N.F. are small arm powders, from the words "fusil" and "nouveau"; B.C. is powder for the field gun, the celebrated "soixante-quinze," from "campagne"; B.S.P. for siege howitzers, from "siège et place"; and B.G.C. for the larger military guns, from "gros calibre."

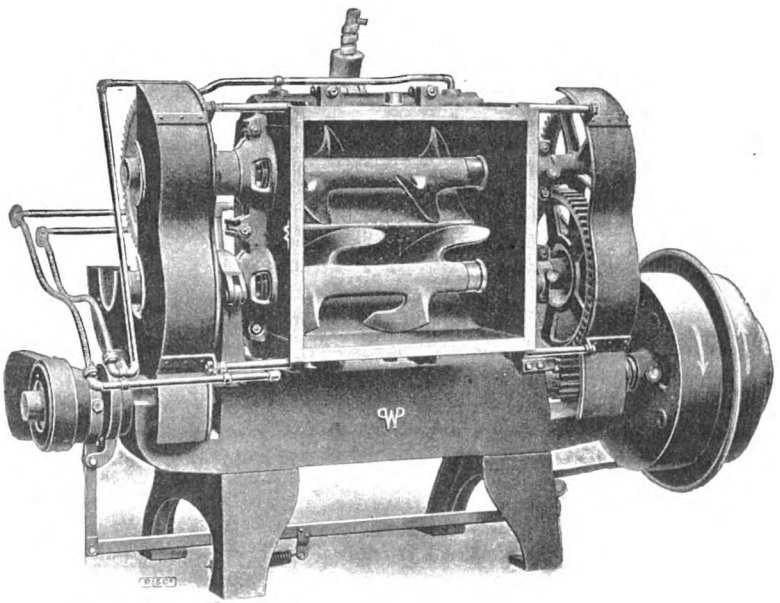

FIG. 16. Incorporating Machine. Trough Tilted, showing Blades

Powders for naval ordnance have the letter M (marine) with an index figure according to the size.

Roumania has adopted a powder similar to Poudre B.

Formerly amyl alcohol was used as stabiliser in Poudre B and old powders were reworked over and over again. A number of spontaneous ignitions occurred, some of which were attended by serious disasters, such as the destruction of the battleship *Jéna* in the Toulon harbour in 1907 and the *Liberté* in the same place in 1911. The reworking was consequently discontinued and diphenylamine, a much more efficient stabiliser, was adopted instead of amyl alcohol.

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In the French powder the fibres of CP_1 are not gelatinised but are merely coated with a gelatinised mass of CP_2. Consequently the powder is somewhat porous. The Russian chemist Mendeléef, working on behalf of his government, devised a nitrocellulose powder made from a single nitrocotton entirely soluble in ether-alcohol and containing about 12·5 per cent. of nitrogen, to which he gave the name "pyro-collodion." The Russian powder contains a small proportion of diphenylamine and is made in the form of round sticks or tubes.

The Americans after trials with powders of different sorts also adopted a pyro-collodion powder. A soluble nitrocellulose containing about 12·5 per cent. nitrogen is gelatinised by means of ether-alcohol and, after filter-

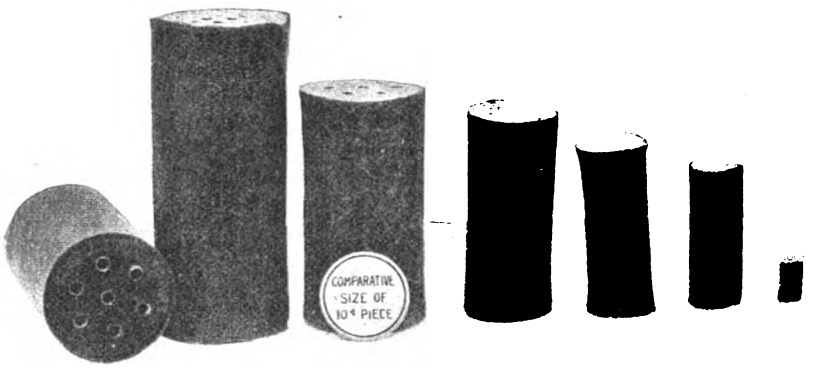

FIG. 17. American Pyro-collodion Powders (from *Appleton's Magazine*)

ing, the stiff dough is pressed by means of powerful hydraulic presses through dies which form it into rods pierced with seven small longitudinal holes. It contains diphenylamine as a stabiliser. In the British Service this powder is known as N.C.T. (Nitrocellulose tubular).

In the manufacture of Ballistite the fibrous structure of the nitrocotton is destroyed, not by the use of a volatile solvent, but by dissolving it in another explosive, nitroglycerine. It is indeed blasting gelatine in which the proportion of nitrocellulose is largely increased. At first benzene was added to facilitate the gelatinisation, and was afterwards evaporated. A better method was discovered later consisting of placing the nitrocotton and nitroglycerine in hot water and agitating them together with compressed air. The dough thus produced is passed between hot rolls, whereby the water is pressed out, and the explosive is made into a sheet. This is folded over and is passed through the rolls again, and the operation is repeated until the material has been converted into a uniform mass. It is then cut into

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FIG. 18. Projectile and Charge for American 16-inch Gun

(From *Smithsonian Report*, 1914, p. 256)

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square flakes, often coated with graphite, and finally blended. It usually contains 40 to 50 per cent. of collodion cotton and 50 to 60 per cent. of nitroglycerine, to which is added a small quantity of some substance to act as a stabiliser. Camphor, calcium carbonate and aniline have been used for this purpose, but diphenylamine is generally added now.

Ballistite was adopted by the Italian Government soon after its invention, but instead of using it in flake form it was drawn out with the aid of a solvent into cords, and hence was given the name "Filite."

In consequence of the severe erosion that ballistite caused in the gun, the Italians reduced the percentage of nitroglycerine to 33 per cent. It then became necessary to use acetone to assist the gelatinisation, and the presence of this solvent made it possible to use a nitro-cellulose only partly soluble in nitroglycerine or ether-alcohol. From 1 to 3 per cent. of a light-coloured mineral jelly was also inserted, so that the powder, which is called Solenite, does not differ very much from Cordite. The nitrccotton used contains 12·4 to 12·6 per cent. N, and about 50 per cent. of it is soluble in ether-alcohol. It is pressed into tubes, which are cut into short lengths. The grains thus obtained are translucent and of a light brown colour, and look somewhat like glass beads.

The Germans adopted ballistite for their navy in 1898 under the name W.P.C/89 : it had much the same composition as the Italian Filite, but was made up in the form of square flakes or cubes. W.P. stands for Wurfelpulver, *i.e.* cube powder. In 1897 and 1900 other powders were introduced less erosive to the guns. These are blackish-grey in colour, and in composition they appear to be much the same as Solenite or Cordite M.D., except that a little diphenylamine is added as a stabilizer, as well as mineral jelly. The powders are made in tubular form and are called R.P.C/97 and R.P.C/00. R.P. stands for Rohrenpulver, *i.e.* tube powder. The Germans use nitroglycerine powder for their large naval guns and for their howitzers, as they consider that they give more regular ballistics in these weapons than nitrocellulose powders. For their small-arms and 77 mm. field guns, etc., they use nitro-cellulose powder of comparatively high nitration containing diphenylamine as a stabiliser, and sometimes some camphor as an auxiliary gelatinising agent. The powder for field guns is made in the form of tubes. They have also introduced a progressive powder with the surface gelatinised by means of a substance called Centralite.

The following particulars as to German military powders are given by Berlin.

Nitrocellulose powders. Colour greyish yellow, or brown, resembling glue.

S.P. Flake powder for rifle 98 and carbine 98.
Pl.P.P. (Platzpatronen-pulver). Blank powder for same weapons.

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Gesch.Bl.P. (Geschütz-Blättchenpulver). Flake powder for the 9 cm. guns 73, 73/88, and the heavy 12 cm. gun.

Gesch.Bl.P. 03 } Powders made by reworking Gesch-Bl.P. and Gr.Bl.P. to make
Gesch.Bl.P. (umg.) } them milder and more stable.

Gr.Bl.P. 03 (Grobes Blättchenpulver). Large flake powder for first use in the 15 cm. ring cannon and 21 cm. ring cannon.

Gr.Bl.P. (umg.). Made by reworking the above.

R.G. 96 } Tubular powders for use in the field gun 96 n/a (127 mm. long).
R.P. 05 }

R.P. 97 and 99 (Rohrenpulver). For use in the various 10 cm. guns (380 mm. long).

R.P. 07. For the 13 cm. gun.

Man.R.P. (Manöver-Ringpulver). Blank ring powder for field guns.

Nitroglycerine powders. Colour black, due to coating of graphite.

W.P. ($\frac{1}{2}$) (Wurfelpulver). Cubic powder, edge of cubes $\frac{1}{2}$ mm. for the 3·7 revolver cannon.

W.P. ($2 \times 2 \times \frac{3}{4}$). For the 5 cm. gun.

W.P. ($4 \times 4 \times 1$). For the light field howitzer.

W.P. (2). For the heavy field howitzer and 21 cm. bronze mortar.

W.P. ($10 \times 10 \times 1\frac{1}{2}$). For the heavy field howitzer 02, and 15 cm. howitzer, and the 21 cm. bronze mortar.

W.P. ($12 \times 12 \times 12$). For the 21 cm. mortar.

Rg.P. (Ringpulver). Short tubular powder for mortars.

Man.St.P. (Manöver-Sternpulver). A porous powder easily ignited, made in the form of stars, colour grey, with yellow spots, for blank cartridges for manœuvres.

In the manufacture of cordite the guncotton is first dried in hot-air stoves. Fixed quantities are then weighed out into waterproof bags which are taken to another house where measured quantities of nitroglycerine are poured in. These two ingredients receive a preliminary mixing by being rubbed by hand through a coarse sieve, which also serves to break up the blocks of loosely compressed guncotton. This "paste" is next placed in an incorporator together with acetone and the machine is run for $3\frac{1}{2}$ hours; the mineral jelly is then added and incorporation is continued for a further $3\frac{1}{2}$ hours. The "dough" thus obtained is then pressed through dies which form it into cords or tubes, which are taken away to stoves where they are dried by means of hot-air or steam. Originally cordite contained more than half its weight of nitroglycerine, but in the South African War this was found to erode the guns too much, so the proportion of nitroglycerine was reduced. Cordite of the modified composition is called M.D. The following shows the compositions:

	Mk. I	M.D.
Guncotton	37	65
Nitroglycerine	58	30
Mineral jelly	5	5

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There has been much controversy as to the relative merits of nitrocellulose and nitroglycerine powders, the former name being given to propellants which contain no nitroglycerine and the latter to those which contain nitroglycerine as well as nitrocellulose. The advantages claimed for nitroglycerine powders are that they give more constant ballistics, do not give backflash when fired, and have at least as good chemical stability as nitrocellulose powders. Their great disadvantage is that the temperature of explosion is high and consequently the erosion of the bore of the gun is very severe.

In spite of the fact that erosion is specially troublesome in the larger guns nitroglycerine powders are used by most of the Powers for their naval and other heavy guns, but France, Russia and the United States use nitrocellulose powders for all purposes. Nitrocellulose powders of large size give up the last portion of solvent very reluctantly in the drying process and it is necessary to leave several per cent. in the finished powder. Moreover, if it were all removed the powder would become too brittle and give high pressures. On keeping, however, some of the solvent may escape and upset the ballistics. Nitroglycerine powders give up their solvent comparatively easily and even the largest sizes can be dried down to about 1 per cent. The presence of the nitroglycerine prevents the material becoming brittle.

In cordite the mineral jelly reduces the temperature of explosion considerably and the powder consequently does not erode the guns much more than some nitrocellulose powders do.

When large guns are fired the combustible powder gases are liable to catch light at the muzzle and burn down the bore, and when the breech is opened this flame may emerge, especially if the gun be pointing to windward. This danger is greater with nitrocellulose powders because the gases they form on explosion are more inflammable than those from nitroglycerine powders. There have been a number of accidents from this cause in the French and American services.

When cannon are fired flames generally appear at the muzzle due to the ignition of the combustible gaseous products. This is objectionable because at night it reveals the position of the gun. The flame can be diminished by the addition of a cooling agent to the powder or a small proportion of a salt of sodium or potassium, but these additions are liable to increase the amount of smoke which is equally objectionable, especially by day. The larger the charge of powder and the greater the amount of heat liberated in its explosion, the greater is the tendency to form muzzle flames.

The form into which a powder is made up has considerable influence on the ballistics. When the powder is ignited it burns with a velocity dependent on the pressure in the chamber of the gun, but it burns regularly by parallel layers. That this is so is clearly seen when a powder of large size is fired from a comparatively short gun; for part of the charge is thrown

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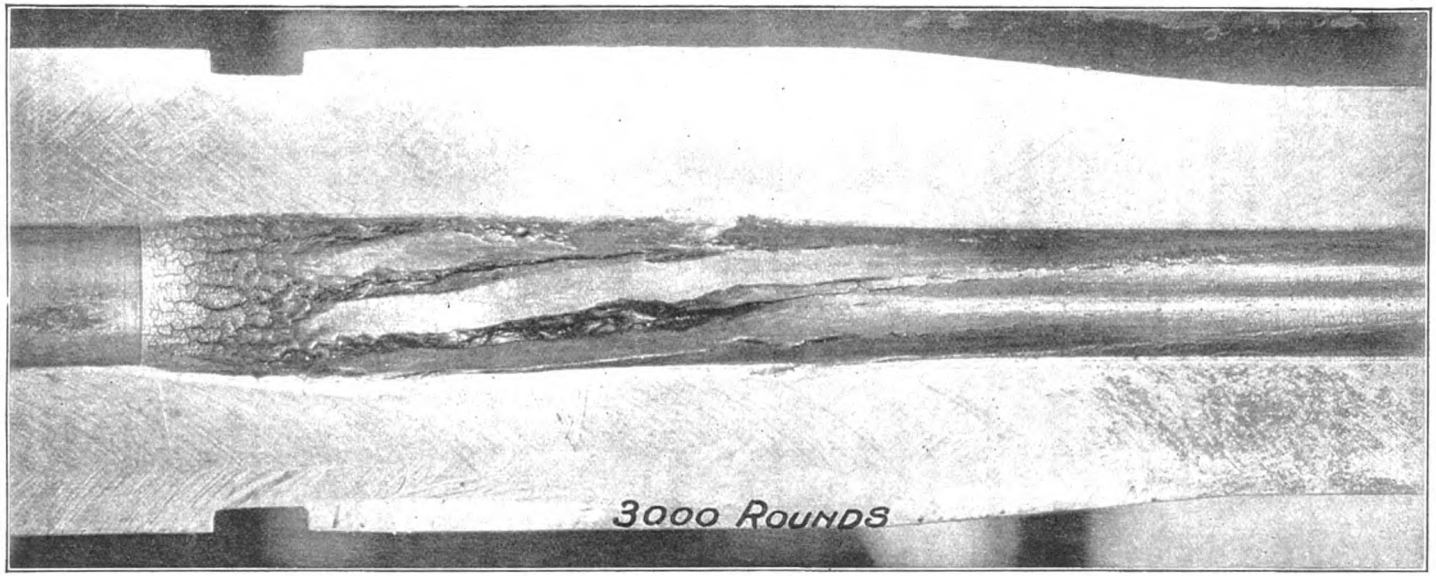

FIG. 19. Cross-Section of Machine-Gun Barrel showing erosion caused by firing 3,000 Rounds with Nitroglycerine Powder

(From *Smithsonian Report*, 1914, p. 257)

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out of the muzzle and is extinguished by the cold air outside. When these grains are picked up and examined, they are seen to have retained their original shape but all the surfaces are uniformly eaten away. If the powder be in the form of cubes or cords the area of surface diminishes as the burning proceeds and consequently the pressure falls off rapidly as the projectile travels down the bore. If it be in the form of tubes or broad tapes or thin flakes the area remains practically constant, and the pressure is maintained better. With a multiperforated tube, such as the American nitrocellulose powder, there is an actual increase of surface. As a gun cannot be used safely with more than a certain pressure in the chamber, and as the velocity of the projectile depends upon the pressures exerted on its base all the time until it leaves the muzzle, it is undesirable that the pressure should fall off too rapidly. Hence the importance of making the powder up into such forms that the surface exposed does not diminish.

The relative rate of burning of the powder charge at different instants can also be altered by treating the surface of the grains. There are substances such as "Centralite" (dimethyl-diphenyl-urea) which dissolve in the surface layer and make the powder burn more slowly at first. Coating the grains with graphite has somewhat the same effect but not to such a great extent.

Any of these powders can be fired from sporting rifles provided they be made up in small sizes. Ballistite, Cordite and various nitrocellulose flake powders are much used for this purpose. Axite is Cordite M.D. with the addition of a little potassium nitrate. Moddite also is a variation of Cordite M.D. but made with a nitrocellulose partially soluble in ether-alcohol.

Powders for shot-guns must be made to burn considerably more rapidly than those for rifles. They may be divided into two classes: "condensed" and "bulk" powders. Condensed powders are completely gelatinised and are made in much the same manner as rifle powders but are in smaller and thinner grains. Sporting ballistite is of this type, and is made in the form of thin flakes about 0·005 inch thick. The advantages claimed for condensed powders are that they leave very little solid residue when burnt, and consequently are free from smoke and "blow-back," and leave but little fouling in the bore, that they are not much affected by exposure to moist air, are very quick and give little recoil. On the other hand, they require special cartridge cases with a cone of pasteboard filling up part of the base, because otherwise the case would not be entirely filled, and too much of the powder would be exposed to the flash of the cap. They are also liable to give abnormally high pressures and are more difficult to manufacture than bulk powders. The normal charge of Sporting Ballistite for a 12-bore gun is only 26 grains.

Bulk powders are so made that the charge for a 12-bore gun occupies the same space in the cartridge as the standard charge of 82 grains of black

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powder, viz. 3 liquid drachms. The grains consist of porous masses of nitrocellulose, more or less completely gelatinised, and mixed with other substances, such as the nitrates of potassium and barium, nitro-derivatives of benzene and toluene and other matters such as lamp-black, wood meal, gum and potassium ferricyanide.

The various ingredients are sometimes milled together in mills similar to those used for the manufacture of gunpowder. The mixture is formed into grains by passing it through a sieve, then dried and partially gelatinised by spraying it with a solvent such as ether-alcohol. This method is, however, varied considerably by different makers.

The older powders, Schultze and Amberite, are 42-grain powders, that is to say the charge required for an ordinary 12-bore cartridge is 42 grains, and this quantity occupies the same space in the cartridge as 82 grains of black sporting powder. Other 42-grain powders are Ruby, Felixite, Primrose Smokeless, Cooppal No. 1 and K.S. Some of these powders are still used extensively, but there is a growing demand for powders of which smaller charges are required, the principal advantage being that they give a decidedly lighter recoil, for the powder products are ejected from the muzzle of the gun with higher velocity than the shot. It is also claimed that they are quicker. Reduction of charge is effected by using a nitrocellulose of higher nitrogen content, and reducing the proportion of other constituents. These changes increase the rate of burning, so in order to prevent the production of dangerous pressures in the gun it is necessary to gelatinise the nitrocellulose more completely. A 33-grain powder can be made in much the same manner as is described above, except that, after the grains have been formed and hardened, a portion of the nitrates is washed out by steeping the materials in water. A well-known 33-grain powder of English manufacture is Smokeless Diamond; Henrite is another of this class: both these are in the form of black grains. E.C. No. 3 is a 33-grain powder too; it is coloured yellow with aurine. Other 33-grain powders are Empire, K.S.G., Lightning, Red Star, Stowmarket Smokeless, Vicmos and Emerald.

By taking a further step in the same direction the charge can be reduced to as little as 30 grains. The nitrocellulose is mixed with a small proportion of "reducers" and several times its weight of barium and potassium nitrates. It is then incorporated in a Werner and Pfleiderer machine with sufficient acetone, or other suitable solvent, to gelatinise it entirely. The dough is then formed into small cubes or prisms by processes similar to those employed for rifle powders, and after drying, the mineral nitrates are dissolved out as completely as possible with warm water. Only about 5 per cent. are left in. Schultze Cube Powder is an instance of 30-grain powder produced by a process of manufacture of this sort. Neonite is another.

The propellant for a trench howitzer has to fulfill much the same require-

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ments as that for a shot-gun: a heavy projectile has to be given a comparatively low muzzle velocity and the gun cannot withstand a high pressure. The difficulty is to obtain constant ballistics with this low pressure in the chamber. It is overcome by using powders of the same types as those for shot-guns. Black powder has been used but gives too much smoke.

Blank powders are used for firing time and other signals, for manœuvres and displays, such as "feux de joie"; in all cases in fact where it is required to make the noise of firing without ejecting a projectile. Difficulty is caused by the fact that there is no heavy projectile to offer resistance to the expansion of the powder gases: consequently as soon as the envelope containing the powder is burst the pressure falls almost to nothing. With black powder this does not matter very much, as the rate of burning is not affected to the same extent by the pressure; for this use can be made of gunpowder which is not good enough for ordinary cartridges. The rate of burning of smokeless powder, on the other hand, is greatly affected by the pressure: there is danger therefore that, if the envelope offer a little too much resistance or the primer be too strong, dangerous pressures may be set up in the gun: and if the resistance or the ignition be too weak the report will be insufficiently loud.

As in the case of shot-gun powders the rapidity of burning is attained by using either a partially gelatinised material, or a completely gelatinised one in a fine state of division. In the British Service the small-arm blank cartridges have a charge of 20 grains of cordite size 20 S.C. S.C. stands for "sliced," and this powder is made by passing strands of cordite about 0·20 inch in diameter through a machine, in which it is cut transversely by rapidly rotating knives into small discs having a thickness of about 0·0055 inch. For ordnance, however, black powder is used generally. In France a special powder is manufactured known as Poudre EF, which is made of nitrocotton and binding material.

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CHAPTER VIII

FIREWORKS

THE preparation of fireworks is the oldest of all the uses to which explosives have been put; directions for making them are given in the writings of Roger Bacon and other works of the thirteenth century, both in Europe and the East. The Chinese were already using them in warfare at that time.

Fireworks are filled with mixtures, which burn energetically and contain in themselves the oxygen necessary for combustion. These mixtures are practically identical with some of those that are used as explosives, and in some circumstances they are liable to explode. Many varieties of fireworks are, however, made to explode, in order to produce a report. One of the materials that is most largely used in pyrotechny is mealed gunpowder, to which substances are added to modify its properties and make it burn more slowly.

FIG. 20. Rocket

The rocket consists of a tube, open at one end, into which is rammed a black powder mixture. A long conical hole is made in the composition (*see* Fig. 20) and a piece of quick-match or other ignition device is applied. The composition burns from the surface of the conical hole outwards, and the products of combustion, largely gaseous, escape at a high velocity through the constricted opening with the result that the rocket is driven forward. For convenience of loading the composition is sometimes compressed into pellets before being placed in the rocket case. The mixtures used vary considerably in composition:

Saltpetre	57–89 per cent.
Charcoal	16–33 „
Sulphur	9–16 „

The compositions that burn most quickly are those that do not differ very much from ordinary gunpowder. The incorporation is generally carried out in drums, but it is not necessary to mix the ingredients very intimately. The charcoal is often left rather coarse, in order that a good trail of sparks may be formed as the rocket rises.

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The ordinary rocket is attached to a stick which projects behind, and serves to maintain the direction as it travels through the air. It is from this that the appliance derives its name, for in Old English and other European languages a distaff was called a "rock." Incendiary rockets were used in warfare as early as the thirteenth century apparently, but seem to have done serious damage only rarely, until they were greatly enlarged and improved about the year 1800, when Col. Congreve devised his war rocket. This consisted of a strong steel tube which had a cast-iron head and a tailpiece, with three conical openings or vents cut away on one side, so that the gas issuing from the body met with resistance on one side only, and so caused the rocket to rotate. The rotation kept the rocket steady during flight and consequently no stick was required. The large war rocket weighed 24 lb. and was about 2 feet long. It was used with great effect during the Napoleonic wars against Copenhagen, at Walcheren and at the battle of Leipzig, but in consequence of the great improvements in artillery it is not used now. The future may see it revived, like the grenade. A powerful rocket with a charge of high explosive in the head and an impact fuse might prove very effective against an enemy shielded from direct fire, and would be comparatively easy to transport in difficult mountain country. Its worst defect is want of accuracy. Major Unge attempted to revive it under the name of "aerial torpedo" for the attack of airships, but for this purpose it does not seem to be suitable.

The name of "aerial torpedo" has also been given, amongst many others, to the shell thrown by some varieties of trench mortars. Some trials have been made by the Germans with war rockets in the present war, but they are unable to compete with guns, howitzers and trench mortars in localities where these can be brought into action.

The life-saving rocket is used by coastguards and others for throwing life-lines on to wrecked ships. It is a powerful rocket so constructed as to burn for a long time and to put only a moderate strain upon the line. The Boxer life-saving rocket consists practically of two rockets arranged in tandem in the same case, so that when the first has finished burning the second starts.

The rocket used for pyrotechnic displays has a cardboard case and a chamber in the forward end, separated by a plug of clay or other material through which passes a piece of quick-match. The chamber contains gunpowder and a number of stars, composed of white or coloured light composition and primed with mealed powder. When the rocket has reached its maximum height and all the rocket composition has burned away, ignition is conveyed by the quick-match to the powder, which explodes and bursts the walls of the chamber. The stars then fall down burning brightly. The signal rockets used for military purposes are constructed in the same way.

Sound rockets, which are also used for signals, have a small charge of

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tonite or other high explosive, which is fired by means of a detonator as soon as the rocket composition has burned away.

Light rockets are used to light up the landscape and reveal the position of the enemy at night. Each rocket usually contains a single star composed of aluminium light composition somewhat similar to that used for photography. This consists of powdered aluminium, or magnesium-aluminium alloy, mixed with oxidising materials such as barium nitrate and potassium chlorate. The tendency is to substitute aluminium powder partly or wholly for the magnesium, as it gives quite as good a light and is cheaper.

Coloured lights are used not only for the stars of rockets but also for Bengal lights and very many other sorts of fireworks. In books devoted to pyrotechny many different formulæ may be found, but it may be stated generally that for

green lights	barium compounds
yellow lights	sodium compounds
blue lights	copper or lead compounds
red lights	strontium compounds

are used. Fire-workers like to use the chlorates of these elements together with sulphur or a sulphide, as such mixtures burn with great brilliancy. But such compositions are decidedly dangerous: not only are they very sensitive to blows and friction, but they are even liable to ignite spontaneously. The sulphur is oxidised by the chlorate to sulphuric acid, which then accelerates the reaction until it becomes so rapid that the mass ignites. Mixtures containing sulphur are considerably worse than those with sulphides, and after a number of fatal accidents had occurred the use of the sulphur-chlorate mixtures was definitely forbidden by Order in Council No. 15 of April 30, 1894. A similar Order has also been issued in India partly because these mixtures were used by Indian anarchists, but in consequence of the difficulty of enforcing such a regulation in a country like India, they are still made by village firework makers and sometimes lead to fatal accidents.

Mixtures of chlorates with the sulphides of arsenic, antimony and copper are also dangerous. Shellac, which is much used for binding the composition together, increases the sensitiveness. Mixtures of chlorates, metallic aluminium and shellac are specially dangerous and may ignite spontaneously if kept at a temperature of 100° F. (38° C.). In many cases the chlorates may be replaced with advantage by the more stable perchlorates. In most countries mixtures of chlorate and sulphur are still allowed. Stars made of chlorate mixtures are rammed into "pill boxes" and are provided with a little priming, as already stated. Those made of nitrate mixtures are generally "naked," as they burn more quietly and require no priming. Sodium chlorate compositions are more dangerous than those containing the potassium salt.

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The following are some examples of coloured fire mixtures:

Green		Yellow		Red	
Barium chlorate	68	Sodium nitrate	70	Potassium chlorate	78
Milk sugar	33	Sulphur	20	Strontium carbonate	15
Shellac	1	Antimony sulphide	7	Shellac	7
		Lampblack	3		

Blue		White	
Potassium chlorate	45	Saltpetre	66
Shellac	5	Sulphur	16
Charcoal	5	Antimony sulphide	16
Basic copper carbonate	10	Gelatine	2
Calomel	35		

The compositions have to be varied somewhat according to the rapidity with which they are required to burn, and the conditions of use. For blue light, alum is sometimes used instead of, or in addition to, copper compounds. To white lights a little lead oxide or nitrate is added in some cases to neutralise the yellow effect due to traces of sodium salts. Calomel (mercurous chloride) is often added, especially to blue and red lights, to increase the luminosity and decrease the rate of burning.

Golden rain is made by mixing powder, such as is used for rockets, with crushed iron or steel turnings or borings. These materials are often added also to rocket mixtures in order to produce a more brilliant trail. If the borings are uncrushed, comparatively few sparks are formed, but they are finer individually and give a good scintillating effect. Magnesium or aluminium powder gives white sparks; copper greenish ones; zinc bluish white and iron red.

Mixtures of chlorates with phosphorus are considerably more dangerous than those with sulphur. They are used, however, in minute charges for alarm corks, throwdowns and caps for toy pistols. Fulminate of silver is used for the same purpose and for bon-bon snaps. This is such a sensitive substance that only very small quantities are made at a time. In England the quantity of fulminate of silver allowed in the work-rooms is usually limited to 1 grain per person.

The railway fog signals used in England consist of flat tins filled with gunpowder and containing a number of percussion caps. Soldered to the top is a strip of lead, by means of which it is attached to the rail. When a wheel of the train passes over it it fires the percussion caps, which explode the gunpowder. The signals must be so constructed that if one explodes it will not fire others in contact with it.

In America "railroad fusees" are used, which are practically coloured lights intended to burn for about ten minutes. The top is provided with a

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little match composition which can be ignited by rubbing on a prepared surface. The most usual colour is red, and formerly they generally contained strontium nitrate, potassium chlorate, sulphur, rosin, charcoal, petroleum grease and sawdust. The mixture of chlorate and sulphur made them liable to spontaneous ignition and unduly sensitive. They have now been rendered safe by the elimination of the sulphur or the substitution of potassium perchlorate for chlorate.

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CHAPTER IX

PROPERTIES OF EXPLOSIVES

THE amount of destruction that can be accomplished by an explosion under the most favourable circumstances is its "power," and it is of importance to know, at any rate roughly, what the power of different explosives is. One of the most important factors affecting this power is the amount of heat which is given out when unit weight of the substance is exploded, and the celebrated French chemist, Berthelot, wrote a treatise on "Explosives and their Power" (la Puissance des Substances explosifs) dealing mainly with this aspect of the subject. The heat may be determined directly by exploding some of the material inside a strong bomb which is immersed in a known volume of water. The rise in temperature of the bomb and the water, etc., affords a measure of the heat evolved. It can also be calculated from the heats of formation of the substances present in the explosive and those formed in the explosion, if these be known.

Another equally important factor is the volume of gas formed. This also can either be measured directly or calculated. A rough measure of the power is afforded by multiplying together the heat evolved and the volume of gas. More elaborate calculations based upon the properties of the gases formed yield a somewhat more reliable figure, but so little is known about the behaviour of gases at very high temperatures and pressures that the results are not altogether reliable.

There are also various devices for measuring the power of explosives directly. The one most used is the Trauzl lead block. This is a cylindrical lead block 200 mm. (7·9 inches) in diameter and height with a central hole 25 mm. (0·985 inch) in diameter and 125 mm. (4·92 inches) deep. Under carefully regulated conditions 10 grammes of the explosives are placed in the bore, tamped with sand and fired with a detonator. The size of the cavity made in the lead is taken as a measure of the power.

Another method is to fire a charge of the explosive in a large bomb pro-

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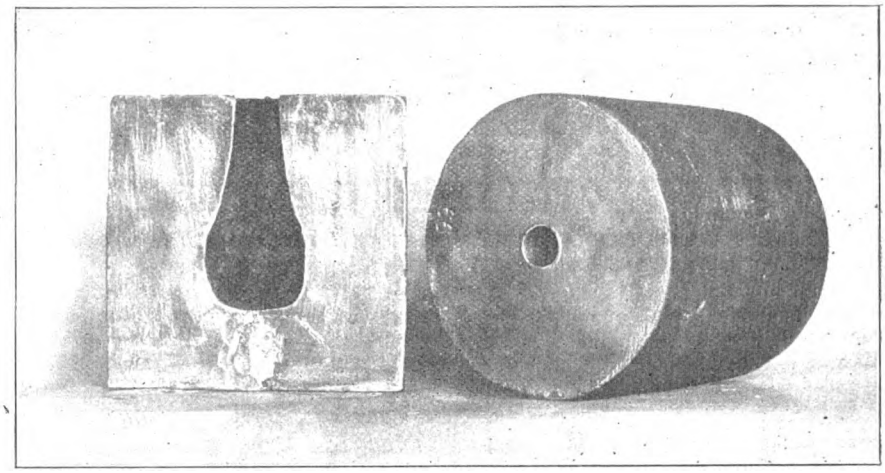

FIG. 21. Trauzl Lead Block (from *Bureau of Mines Bulletin*, No. 15)

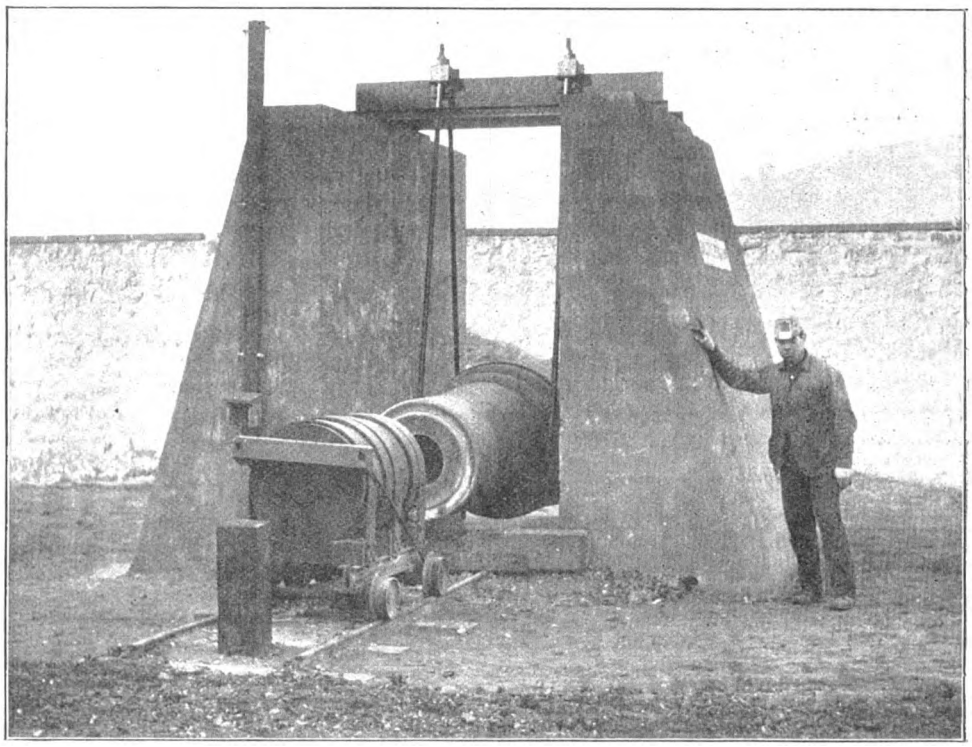

FIG. 22. Ballistic Pendulum (from *Bureau of Mines Bulletin*, No. 15)

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vided with means for measuring the pressure generated, which is proportional to the kinetic energy of the gases at the moment of explosion. The following table gives the results of determinations made with various explosives :

	Volume of gas c.c.	Quantity of heat	$\frac{\text{Heat} \times \text{vol.}}{1000}$	Pressure	Trauzl test
Blasting gelatine . . .	851	1422	1210	70·4	650
Gelignite (65 per cent.) . .	487	1321	643	55·4	560
Dynamite No. 1 . . .	536	1170	627	48·2	520
Donarite	1023	836	856	48·7	500
Carbonite	729	576	420	26·6	265
Gunpowder	386	574	228	18·7	108

Donarite consists of ammonium nitrate and trinitrotoluene with a little nitroglycerine and flour. The Trauzl lead block does not give satisfactory results with slow explosives like gunpowder. The result quoted above was obtained by tamping with Portland cement, but even so is too low.

There is another device which yields good results with explosives like gunpowder, as well as with high explosives ; this is the ballistic pendulum. It consists of a heavy mortar suspended from a horizontal axis so that its swing can be measured. The explosive, together with a certain quantity of stemming, is fired into its mouth from a strong steel gun. The length of the swing imparted to the mortar is a measure of the power of the explosive. The results are in good agreement with those obtained in actual use. Some careful trials in coal mines yielded the following comparative figures :

Explosive	Coal-getting trials	Ballistic pendulum
Bobbinite	100	100
Carbonite	177	159
Saxonite	257	246
Ammonite	273	261

Such trials in the mine are too expensive and troublesome to be carried out very often, but in France the following comparative results have been obtained :

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	Heat evolved	Pressure in bomb	Trauzl test	Industrial result
Blasting gelatine	100	100	100	100
Dynamite No. 1	73	67	66	67
Grisoutine roche	41	72	66	69
„ couche	37	60	50	53
Blasting gunpowder . . .	43	28	31	31

As has already been mentioned, the calculation of the temperature attained during the explosion is not very reliable. It is, however, of considerable importance in the case of smokeless powders, as the erosion of the gun depends principally on the temperature of the powder gases, and in the case of explosives for use in coal mines also it is important that the temperatures be not too high. The following results calculated by Will are therefore of interest: they give at least an indication of the comparative temperatures produced by the different explosives:

	Heat generated Cals./Kg.	Gas evolved Litres/Kg.	Calculated temperature
Blasting gelatine	1640	710	3540° C.
Nitroglycerine	1580	712	3470
Dynamite No 1.	1290	628	3160
Nitroglycerine powder (40 per cent.)	1290	840	2900
Guncotton (13 per cent. N) . .	1100	859	2710
Nitrocellulose powder . . .	900	830	2400
Collodion cotton (12 per cent. N) .	730	974	1940
Ammonium nitrate explosive (10 per cent. mononitronaphthalene) .	930	925	2120
Picric acid	810	877	2430
Black powder	685	285	2770
Ammonium nitrate . . .	630	937	2120
Mercury fulminate . . .	410	314	3530

Another important factor governing the choice of an explosive is its violence, which depends upon the time required for it to detonate. Although this time is always extremely small, the differences between various types of explosive are considerable, and have a great influence on the effects produced. There are two methods in use for the determination of the velocity

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of detonation: the absolute method and Dautriche's method. In the former a string of cartridges of the explosive is made up, and at two or more points in the string electric wires are passed through or over it. Each of these wires is connected with an appliance which makes a mark, when the current through it is interrupted, on a drum rotating at a known speed. From the position of these marks the interval of time between the breaking of the two circuits can easily be calculated, and this is the time that the wave of detonation has taken to travel between the two points in the string of cartridges.

In Dautriche's method use is made of the fact that, if in a column of explosive, waves of detonation be started from both ends, at the point where they meet there is extra violence. If a piece of detonating fuse be laid on a slab of lead and detonation be started from both ends of the fuse, at the point where the detonation waves meet a sharp and distinct transverse line is made on the lead. At two points in a cartridge of the explosive to be tested detonators are inserted, and into the open ends of the detonators are introduced the two ends of a piece of detonating fuse, which consists of lead tubing filled with trinitrotoluene. The velocity of detonation of the fuse must be known, but this is determined by the suppliers by the absolute method. The middle part of the fuse is attached to a lead slab and its centre point is marked on the lead. The cartridge is then fired by means of a third detonator. This starts waves of detonation travelling along the fuse from both ends, but the two waves do not start at the same instant. Consequently they do not meet in the centre, but at a point somewhat removed from it. The distance of this point from the centre and the known velocity of detonation of the fuse give, by a simple calculation, the velocity of detonation of the explosive under test. This method has the advantage of simplicity and requires no expensive appliances for carrying it out.

The velocity of detonation is but little affected by the diameter of the column of explosive, unless it be very thin, nor by the amount of confinement, provided it be sufficient to cause the explosive to detonate completely. Some explosives, such as picric acid, trotyl and dynamite, can be detonated completely and with their full velocity even when quite unconfined. The strength of the detonator or primer also has little effect, except in the first part of the column of explosive. The density of the explosive on the other hand has a great influence on the velocity of detonation: the more densely the explosive is pressed the greater is the velocity, but with some explosives, Cheddite for instance, there is an apparent falling off of the velocity of detonation when a certain limiting density has been exceeded. This, however, is due to the diminution of sensitiveness of the explosive at these high densities, which causes the wave of detonation to die gradually away as it proceeds. The following table gives the results of some determinations of the velocity of detonation:

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	Density	Velocity of detonation. Metres per sec.
Mercury fulminate	1·25	2474
Detonating fuse (trotyl in lead tube)	—	6880
Trinitrotoluene (trotyl)	1·0	4950
	1·4	6300
	1·6	7000
Trinitro-benzene	1·4	6500
	1·6	7150
Picric acid (Lyddite)	1·0	5200
	1·4	6800
	1·6	7300
Guncotton, dry	0·9	3900
	1·2	4300
,, wet (15 per cent. water)	—	5540
Tetranitro-methyl-aniline (tetryl)	1·53	7150
	1·63	7215
Trinitro-cresol	1·62	6850
Dinitro-benzene	1·5	6000
Dynamite No. 1	0·79	2400
	1·34	3670
	1·54	5230
	1·62	6800
Ammonal	0·9	3450
Grisounite N_1C	—	3635
Cheddite O_2	—	2750
Carbonite	1·08	2440
Gunpowder	1·04	200 to 300
American blasting powder F.F.	—	469
Judson powder	—	1018

The behaviour of nitroglycerine is peculiar. If detonated with a detonator of medium strength, results are obtained ranging from 1,300 to 2,300 metres per second; but if fired with a powerful primer the velocity of detonation is about 7,200. Ungelatinised nitroglycerine explosives are comparatively easy to detonate. Their velocities of detonation increase with rise of density and with the percentage of nitroglycerine. Only at very high densities do they become difficult to detonate. Gelatinised nitroglycerine explosives on the other hand have, like liquid nitroglycerine, two velocities of detonation depending upon whether a detonator only is used or a primer of some explosive such as dynamite No. 1. The following are the velocities of detonation of American dynamites:

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Grade	10 per cent.	30 per cent.	40 per cent.	50 per cent.	60 per cent.	75 per cent.
Straight dynamite . .	2100	4200	4800	5300	5800	6200
Gelatine dynamite . .	—	—	2100	2200	2200	2100
„ „ with primer	—	—	5600	6000	6700	7000
Ammonia dynamite . .	—	3600	4200	4300	3000	—

In course of time gelatinised explosives get stiffer and tend more and more to detonate with the lower velocity, and consequently require stronger primers to develop their full violence.

The power of the explosive is the governing factor for shifting rock, but for breaking it up, especially if it be very hard, the violence or "brisance" is the property that counts. A measure of the brisance is obtained by multiplying the power by the velocity of detonation. The following table shows the brisance of a number of explosives calculated in this way, the figures obtained being divided by 10,000 to make them of a convenient magnitude.

Explosive	Density	Trauzl test	Velocity of detonation	Brisance
Blasting gelatine (with primer) .	1·6	650	7500	780
Gelatine dynamite (with primer) .	1·6	490	6700	525
Dynamite No. 1	1·58	510	6000	486
Picric acid	1·7	320	7700	420
Picric acid	1·6	320	7300	374
Trinitrotoluene	1·6	290	7000	324
Guncotton	1·12	420	5300	249
Blasting gelatine (without primer) .	1·6	650	2200	210
Mercury fulminate	2·5	213	3920	209
Cheddite 60	1·4	288	3100	125
Carbonite	1·08	266	2440	70
Gunpowder	1·04	187	280	5

The brisance can also be measured directly by exploding a cartridge placed on the top of a steel piston, which rests on a small copper cylinder or "crusher." If a number of different explosives are thus tested under identical conditions, the shortening of the coppers gives a measure of the relative brisance. The cartridge must be detonated by a detonator inserted in its top end, for there is considerably more violence exerted in the direction of the wave of detonation than in any other.

The length of the cartridge should be at least three and a half times its

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diameter: if this condition be fulfilled the results are apparently unaffected by variations in the length.

The sensitiveness of an explosive affects not only its safety in handling and use, but also its suitability for various purposes. A commercial explosive must be so insensitive to blows and friction that there is no danger of its exploding unexpectedly, provided that reasonable precautions be taken, but it must not be so insensitive to detonation that it cannot be fired with certainty by a detonator containing not more than 2 grammes of fulminate of mercury. Military explosives must be specially insensitive to blows and friction; as a rule they are so insensitive to detonation that a primer must be used in addition to a detonator. On the other hand an explosive used for charging percussion caps must be decidedly sensitive to blows, and one used for filling detonators must be sensitive to flame. Confusion is sometimes made between sensitiveness and power, and a very sensitive explosive is often considered very powerful by those who have not studied the matter specially, because it gives rise to destructive accidents. There is, however, no necessary connection between sensitiveness and power or violence: the very sensitive explosives are not as a rule very powerful, and the most powerful ones, blasting gelatine for instance, are not particularly sensitive.

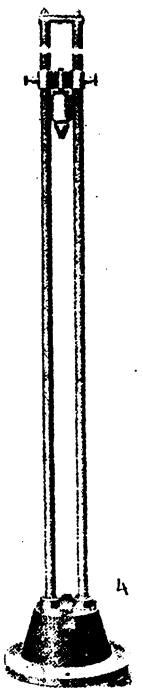

FIG. 23. Falling Weight Apparatus (E. A. Lentz, Berlin)

Sensitiveness to blows is measured by means of the falling weight apparatus, a form of which is shown in Fig. 23. On a hardened steel anvil is placed a small quantity of the explosive, 0·05 to 0·1 gramme. On this is placed a hard steel bolt, on to which a weight of 2 or 10 kilogrammes is allowed to fall from a known height, and observation is made whether the substance explodes. The experiment is repeated with fresh portions of explosive until the length of drop is found which is just enough to cause explosion.

Sensitiveness to friction does not lend itself so readily to accurate measurement. A rough test may be made by rubbing a little of the explosive with pestle and mortar. A test which combines impact and friction consists in hitting the substance a glancing blow with a mallet or the end of a broom-stick. Military explosives are often tested by firing rifle bullets into them, and by other trials which imitate the conditions that the materials may be subjected to on active service.

Explosives vary greatly in the ease with which they can be ignited by heat

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or sparks. Some, such as fine grain gunpowder and fulminate, are ignited by the small flame from a piece of safety fuse. Others, such as blasting gelatine and cordite, are more difficult to light, but burn fiercely when once started. Many ammonium nitrate explosives are very difficult to ignite, and the flame tends to die out even when it is started.

Explosives may be classified according to their composition and their sensitiveness. The following table gives a classification which has been suggested and is based on actual tests. The figures in brackets are the results of falling weight tests, being the heights in centimetres from which a 2 kg. weight must be dropped to cause explosion.

Class I. Cap compositions and substances of similar sensitiveness, which detonate on ignition and are not allowed to be transported (0 to 7).

Mercury fulminate (2)
Nitroglycerine (4)
Picrates of lead (5), iron (7) and copper (7)

Class II. Dynamites. Very sensitive to blows, burn vigorously when ignited, and are liable to explode (7 to 25).

Dynamite No. 1.	(7)
Blasting gelatine.	(7)
Guncotton, dry	(10)

Class III. (26 to 100).

(*a*) Black powder. Not very sensitive to blows. Easily ignited, and is then liable to explode (70 to 100).

(*b*) Chlorate explosives, such as Cheddite. Moderately sensitive to blows. Difficult to light, not ignited by safety fuse, and not liable to explode under ordinary circumstances (about 35).

(*c*) Aromatic nitro-compounds. Sensitive to blows. Difficult to light, not ignited by safety fuse. May explode.

Tetryl	(40 to 65)
Picric acid (Lyddite) . . .	(35 to 95)
Trinitrotoluene (trotyl) . . .	(57 to 180)
Trinitro-cresol	(30)
Ammonium picrate . . .	(80)

(*d*) Nitrocellulose with 15 per cent. water. Little sensitive to blows. Difficult to light, not ignited by safety fuse. May explode (85 to 100).

(*e*) Smokeless powders. Fairly sensitive to blows. Comparatively easy to light, burn rapidly when ignited with safety fuse. Not likely to explode (20 to 50).

Class IV. (100 to 200).

(*a*) Ammonium nitrate explosives, etc. Little sensitive to blows. Difficult to light, not ignited by safety fuse. Not likely to explode under ordinary circumstances. (105 and upwards.)

(*b*) Aromatic nitro-compounds with lower nitrogen content than Class III (*c*).

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Little sensitive to blows. Difficult to light, not ignited by safety fuse. Not liable to explode.

Dinitro-benzene	(120)
Dinitro-phenol	(150)
Trinitro-xylene	(170)
Trinitro-naphthalene	(175)

(c) Nitrocellulose with over 20 per cent. water. Insensitive to blows. Difficult to light, not ignited by safety fuse. Not liable to explode (more than 185).

In the British Empire explosives are classified according to the substances they contain and the form in which they are made up. The following are the main classes :

Class 1	Gunpowder
,, 2	Nitrate mixture
,, 3	Nitro-compound
,, 4	Chlorate mixture
,, 5	Fulminate
,, 6	Ammunition
,, 7	Firework

Class 1 comprises only gunpowder, but has recently been extended to include that made with sodium nitrate. Class 3 comprises nitroglycerine and nitrocotton as well as the substances that chemists call nitro-compounds, also all mixtures containing these substances. In division 1 of this class are the explosives containing nitroglycerine or other liquid "nitro-compound," in division 2 those not containing it. Class 2 comprises explosives containing a mineral nitrate, such as saltpetre or ammonium nitrate and not falling within class 1 or 3. Class 4 does not include perchlorate explosives ; these are in class 2. Class 5 includes all substances which are highly sensitive, such as lead azide and mixtures of chlorate and phosphorus. Class 6 includes amongst other articles cartridges for blasting and for cannon. Full details of the classification are given in the *Guide to the Explosives Act* and in the Annual Reports of H.M. Inspectors of Explosives.

Sensitiveness to detonation is ascertained by firing cartridges of an explosive with detonators of varying strength to discover the weakest that will detonate it completely. The action of fulminate of mercury and similar substances resembles that of a blow rather than of a flame, so that the results of this test are on the whole parallel with those obtained by falling weight test. Explosives for use in coal mines, when tested for safety, are fired into the testing galleries without any stemming, so that it is necessary that they should detonate completely when fired unconfined with a No. 7 or 8 detonator. Explosives for military purposes must also detonate unconfined, but those usually used, trinitrotoluene, picric acid and wet guncotton, require special detonators or a priming of some powerful explosive. The following

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explosives are placed in order of their sensitiveness to detonation, the most sensitive coming first :

Tetryl
Dry guncotton
Picric acid
Trinitro-cresol
Trinitro-benzene
Trinitrotoluene
Trinitro-anisole
Trinitro-xylene.

The detonators used for this test must, of course, be reliable and uniform in strength. The density of the explosive greatly influences its sensitiveness to detonation : the denser it is, the more difficult it becomes to detonate it. At a high density many ammonium nitrate and chlorate explosives become practically inexplosive ; even if detonation be started by means of a powerful priming, it is not propagated throughout the mass, but dies away scattering part of the explosive unconsumed. Substances are generally less difficult to detonate when reduced to powder than when in large crystals, but the powder is less sensitive to blows. From a blow the fine material apparently escapes without being subjected to much shock, but the effect of the detonator is concentrated on a smaller mass of material. If unconfined, a finely powdered explosive may be scattered without being detonated completely, but if confined it is more easily detonated than the coarse crystalline material. Frozen nitro-glycerine explosives are much less sensitive to detonation, whereas to blows under some conditions they are more sensitive.

At low temperatures explosives become less sensitive, and at high temperatures more sensitive, both to blows and to detonation.

An allied property is that of transmitting detonation from one cartridge to another across the intervening space by " influence." The more sensitive an explosive is, the greater is the distance at which it can be exploded, but the distance is also affected by the violence of the impulse given by the first cartridge. Another factor is the nature of the surface on which the cartridges are resting ; steel or hard rock favours the transmission more than soft earth or sand.

Total or partial failure to detonate is a frequent cause of accidents, as the explosive is liable to go off during subsequent handling of the material that has been blasted. Accidents also occur in drilling fresh holes near exploded charges.

The density of a substance is the mass contained in unit volume, and is expressed as the weight compared with that of an equal volume of water. The maximum density of an explosive can be ascertained by calculating the mean of the densities of the constituents, but in explosives, as made and used, there are nearly always pores and air spaces, and consequently the actual

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density of the explosive is considerably less than the maximum density. In gunpowder, for instance, the densities of three constituents are all slightly over 2, but the density of the powder is only 1·6 to 1·8 according to the amount of compression employed in manufacture. This is the density of the grains, but between the grains also there are air spaces, and consequently the "gravimetric density" is only 0·915 to 0·98. The "density of loading" in the gun is the weight of the charge divided by the weight of water which would fill the chamber. This is again considerably less than the gravimetric density, as free space is always left in the chamber to diminish the pressure and erosion.

Some substances tend to take up moisture from the air and become wet. Salts like ammonium nitrate, sodium nitrate and sodium chlorate, which are very soluble in water, possess this property in a high degree. Absorption of water is very injurious to explosives, and those that contain these substances must consequently be kept from contact with the air, either by sealing them up in metal containers or by coating the cartridge with waterproofing material such as paraffin wax.

Nitrocellulose also tends to take up a limited amount of moisture from the air, especially in damp weather. When moist it becomes less explosive.

Explosives containing nitroglycerine are liable under certain circumstances to sweat out or exude some of this substance, and this is a source of serious danger; kieselguhr dynamite, for instance, gives up practically the whole of its nitroglycerine if it becomes wet. If the guhr has not been properly ignited, or if it be of an insufficiently absorbent nature, this tendency is much increased. American dynamites, containing as they do ungelatinised nitroglycerine absorbed in a comparatively small quantity of wood meal, together with a deliquescent salt, are particularly liable to exude.

Gelatinised explosives are liable to become too liquid at a moderately high temperature, if the collodion cotton be of an unsuitable character, or if there be not enough of it.

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CHAPTER X

IGNITION AND DETONATION

In the last chapter it was shown how explosions vary in power and violence. In this one the development of the explosive wave will be discussed and the methods for initiating it. When an explosive, such as a smokeless powder, is "ignited," it burns from the surface inwards in parallel layers with a velocity which depends upon the pressure, but even under several thousand atmospheres, never exceeds a few metres per second: the ignition is communicated from layer to layer by the heat generated. On the other hand, when an explosive is detonated, the wave of detonation proceeds apparently through the mass of unaltered explosive with a velocity of several thousand metres per second, changing the material as it proceeds: in this case the explosion is communicated by pressure, but possibly this pressure acts by suddenly raising the temperature by compression.

A mechanical mixture of different substances, no one of which is able to explode by itself, such as black powder, cannot be made to detonate properly, because the chemical change can only take place at the points where the oxidiser and the combustible substances are in contact. Even under the most severe conditions as to pressure and initial shock, the velocity of explosion does not exceed about 300 metres per second. But if saltpetre be replaced by potassium chlorate, which can be detonated even when not mixed with combustibles, the case is quite altered and a high explosive is obtained, the velocity of detonation of which is several thousand metres per second.

When gunpowder is ignited it burns rapidly, even if unconfined. The porosity of even highly compressed powder facilitates the spread of the flame. The rate of burning is affected comparatively little by pressure: hence the use of fine grain powder to ignite cannon cartridges.

Nitric esters, such as nitroglycerine and guncotton, do not attain a very high rate of combustion when unconfined, unless in a state of fine division. This is apparently due to the fact that under these conditions, the decom-

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position takes a different course from that which is followed when they are exploded in a confined space: the nitrogen is mostly set free in the form of nitric oxide or peroxide, and the heat liberated is very much less.

In the early days gunpowder was always ignited by means of a flame; later sparks from a flint and steel were utilised to light a priming of mealed powder, which communicated the flame to the charge. Not until the nineteenth century was use made of small quantities of sensitive explosives that could be ignited by a blow. It was the discovery of fulminate of mercury which rendered this possible, and this substance is still an essential constituent of most cap compositions. When used by itself in sufficient quantity to ignite gunpowder with certainty, the fulminate produces such a sudden pressure that it deforms the cap. Therefore it is mixed with other substances which diminish its violence and at the same time increase the heat of explosion. Saltpetre, sulphur and mealed powder were formerly added, but now potassium chlorate and sulphide of antimony are employed more frequently; some cap compositions contain all these constituents. Ground glass has also been used to increase sensitiveness, but it is not necessary when fulminate is present, and being chemically inactive it, of course, diminishes the power of the cap. For use with smokeless powders, cap composition should not contain more than about 20 per cent. of fulminate, otherwise the pressure generated will be too high. Numerous attempts have been made to devise cap compositions containing no fulminate, such as a mixture of chlorate of potash and sulpho-cyanide of lead, but although a considerable degree of success has apparently been achieved such compositions have not come into general use, probably on account of the difficulty in attaining the uniformity necessary with mixtures containing no one constituent which is both sensitive and explosive, especially as intimate mixing is from the nature of the material impossible.

In the case of ordnance the conditions are somewhat different from those in small-arms: a larger quantity of material can be used, and a greater amount of force is available. Compositions can therefore be used containing no fulminate. They usually consist of potassium chlorate and antimony sulphide, together with a little sulphur to facilitate ignition and some glass powder to increase sensitiveness. The flash from this is communicated to some black powder, which in turn ignites the cartridge.

For the ignition of powders in fire-arms, heat only is required; for the detonation of high explosives, on the other hand, a very sudden and intense blow is necessary, and this can only be obtained by means of an explosive which itself detonates with a velocity of several thousand metres per second. Detonators are always fired by means of heat supplied either by a burning fuse, or by a priming ignited by an electric current. When a light is applied to fulminate, at first it only burns with a velocity of about 10 metres per

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second, but the reaction becomes more and more rapid, and within an interval of time, which is probably not more than $\frac{1}{3000}$th of a second, detonation sets in.

Fulminate of mercury is made by dissolving mercury (quicksilver) in nitric acid and mixing the solution with alcohol. A reaction sets in with formation of fumes, and the fulminate appears in the liquid as minute crystals, which are seen under the microscope to be in the form of octahedra. The fulminate of mercury, $Hg(ONC)_2$, is washed with water until free from acid, and is kept in the wet state until actually required. Then it is dried at a gentle heat.

Various other substances have been proposed as substitutes for fulminate, but the only one that has been tried on a manufacturing scale is lead azide, PbN_6, which is made by precipitating sodium azide, NaN_3, with lead acetate. Even this has not been used very extensively, however, although it is cheaper than fulminate and is said to be more effective and more permanent. One objection to it is that it sometimes forms large crystals which are very sensitive and consequently extremely dangerous.

Special precautions must be observed when dealing with the very sensitive substances used for charging caps, detonators and other igniters; there is far more danger of explosion than there is with other explosives. The danger is diminished by restricting the quantities that are allowed to be present in any one building. As the amount of explosive in each cap or detonator is small, this restriction does not interfere seriously with the work. The total quantities dealt with are not small, however, for even before the War it was estimated that 100 tons of fulminate of mercury were made in Germany every year, and a single factory in Great Britain manufactured more than double this quantity. The various constituents, before mixing, are sifted through fine sieves to remove all gross gritty particles. The fulminate and the explosive mixtures are kept and transported in small boxes of papier-mâché or other soft smooth material. In those buildings where quantities of a pound or more may be present *en masse*, the floors should be covered with linoleum or other soft stuff, and the workers should all wear felt slippers or only socks. The greatest cleanliness should be observed.

The mixing and drying operations are specially dangerous. The mixing of the composition was at one time done in a very simple way by placing the ingredients on a piece of paper and then stirring them with a goose feather, or lifting first one corner of the paper and then another. Under these conditions it was never possible to protect the worker adequately, and with such very sensitive material there is always great danger of an explosion. Now the mixing is either carried out wet, or it is done in a "jelly-bag."

In the wet process, the constituents are worked together in a wooden mortar in the form of mud with a solution of gum or gelatine, which

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helps to bind them together. In the jelly-bag method the constituents are placed in a conical bag together with soft rubber balls. The apex of the bag is raised and lowered to mix the ingredients together, the whole operation being conducted behind an iron shield, so that there is very little danger. After mixing for a few minutes the apex of the bag is pulled right up and the contents fall through a coarse sieve, which retains the rubber balls but allows the composition to pass into a box made of papier-mâché or other soft material.

The mixed cap composition is taken to the charging machine where it is measured out and pressed into the varnished copper capsules which form the caps of the cartridges. The capsules are fitted into a plate or "hand," which has a large number of depressions, each just large enough to take a capsule; there may be as many as 1,000 of these depressions, 40 rows of 25 each.

The charging machine consists essentially of several brass or bronze plates, each perforated with a number of holes corresponding to the depressions in the "hand." Each hole in the top plate is just large enough to take the quantity of composition required for one cap. A little more than enough composition to fill all the caps is placed on the plate, and then with a piece of soft cloth or rubber the worker passes it over the plate and so fills all the holes. As the charge of each is only 0·3 to 0·6 grain (0·02 to 0·04 gramme) the total quantity of explosive is not much more than 40 grammes, and the explosion of this would not do very serious damage, provided it be not allowed to spread to more of the composition. The stock of composition must therefore be kept in a safe place at some little distance. By a slight movement of the second plate each charge is now caused to fall into its cap. This movement is produced by means of a long rod, so that the worker is not near the explosive.

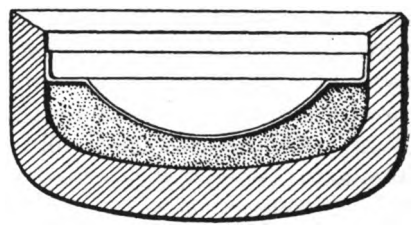

FIG. 24. Percussion Cap. Magnified 10 Diameters

The charges have next to be pressed. This is carried out in a machine which has a row of pistons that are made to descend on to the caps. Each piston is weighted with a separate weight, connected to it through a system of levers, so that not more than a certain pressure, say 2 cwt., can be exerted on each cap. When one row of caps has been pressed, the hand moves forward automatically, so as to bring the next row under the pistons. The surface of the composition is then covered with a thin coat of varnish, and sometimes also with tin-foil.

The following are some fulminate compositions that are used:

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	Austrian		English Small-Arms	
	Small-arm	Shot-gun	Gunpowder	Cordite
Mercury fulminate	13·7	33·9	37·5	19·0
Potassium chlorate	41·5	21·6	37·5	33·3
Antimony sulphide	33·4	—	25·0	42·9
Glass powder	10·7	43·2	—	—
Gelatine	0·7	1·3	—	—
Sulphur	—	—	—	2·4
Mealed powder	—	—	—	2·4

The proportion of glass in the second mixture is very large; in England compositions for shot-gun caps often contain no glass powder.

For the percussion primers of quick-firing gun ammunition the conditions are somewhat different. Firstly, there is more force available, and consequently the composition need not be so sensitive; and secondly, the flash is not required to ignite the powder charge directly, but is first communicated to a small quantity of fine-grain black powder, which in turn ignites the smokeless powder; consequently these caps do not require to be so uniform in their effects as those used for small-arms. The compositions generally contain no fulminate, but consist principally of potassium chlorate and antimony sulphide. Fig. 25 shows the construction of a German percussion primer. The percussion cap is held in place by the screwed anvil, through which there is a perforation permitting the flash to ignite some fine grain powder. Over this there is a pellet of compressed powder, also with a central perforation, held in position by a disc of shirting, and a brass plate with a fire-hole, held down by the turned-over edge of the primer. After it has been assembled the primer is varnished.

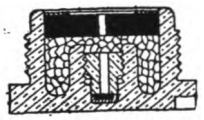

Fig. 25. Percussion Primer for Quick-firing Ammunition

The friction tubes for igniting gun cartridges that are not enclosed in metal cases are constructed on much the same principle, except that the pellet of composition is ignited by the friction of a bar or wire pulled or pushed through it, instead of by the blow of a striker or bolt. As the tube has to be inserted through a hole in the wall or breech of a gun, it must be several inches long. The tube is filled with powder grains or pellets, which carry the flash well into the chamber of the gun. At the top of the tube is the pellet of composition, which is made of a mixture similar to that used for the percussion primers. The following is a composition used in Austrian friction tubes:

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Potassium chlorate	66·2 per cent.
Antimony sulphide	33·1 ,,
Gum arabic	0·7 ,,

Naval and other large guns are often fired electrically. For this purpose tubes are used in which the friction pellet is replaced by some priming composition, consisting of a mixture of mealed powder and guncotton dust, or other easily ignited material. Through it passes a short piece of fine platinum wire, the two ends of which are connected with two copper wires that can be joined to the poles of a battery. The general construction of the electric tube resembles that of an electric detonator, except that the fulminate is replaced by black powder, and the tube is more solidly constructed. All igniting tubes, whether friction or electric, must be so designed that the powder gases cannot blow out through the outer end. The flame from the tube does not suffice, however, to ignite the cartridge which consequently has to be provided with an igniter. This generally consists of fine-grain black powder contained in a bag or pocket covering the end of the cartridge. The quantity is generally from ½ to 2 per cent. of the weight of the smokeless powder. There are various objections to the use of black powder for this purpose, and attempts have been made to find some other material that may be substituted for it. One objection is that this priming considerably increases the amount of smoke that is formed when the charge is fired. For guns of small calibre ungelatinised guncotton in the form of yarn is sometimes used, but no priming gives such regular ballistics as black powder, especially in the big guns. Smokeless powders of small size have been tried, but not always with success. Powder in the form of strip, tube or cord ignites more rapidly and uniformly than flake or cube powder, because in the former case the flame can spread without delay to the further end of the cartridge.

Fuses for shell contain percussion caps, which in the case of percussion fuses are fired by the shock of impact, and in the case of time fuses by the shock of discharge of the gun, either directly or indirectly. The caps are of copper and generally similar in form to those of small-arm cartridges, except that they are often perforated to allow the flash to escape in the opposite direction to the needle. The caps are usually filled with cap composition, more rarely with fulminate alone, and are then more accurately called detonators. The cap for the ordinary German time and percussion fuse is cylindrical, 4·7 mm. in diameter and 6 mm. high; in the base there is a hole 2.5 mm. in diameter. Into it is first placed a piece of copper foil, then 0·092 gramme of a mixture of the composition:

Fulminate of mercury	16·0
Potassium chlorate	51·3
Antimony sulphide	32·0
Gelatine	0·7

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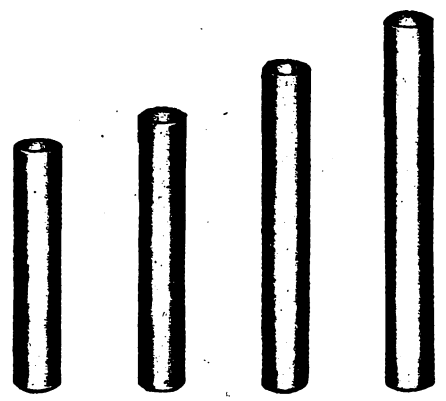
then a disc of tin-foil, and the whole is pressed at 2·3 to 2·4 kg. per sq. cm., so that it occupies a height of 2·6 to 2·9 mm. in the copper cap.

Detonators are manufactured in much the same way as percussion caps, but in consequence of the greater violence of the charge and the far greater quantity in each, much more stringent precautions must be taken for the protection of the workers. The capsules are drawn copper tubes without joint, closed at one end. Of these 100 are placed in holes in a plate or "jig." The filling and pressing operations are conducted in somewhat the same way as with percussion caps.

Detonators of different strengths are distinguished by numbers which are the same in all countries:

No.	Usual external dimensions of tube		Charge	
	Length mm.	Diam. mm.	Grammes	Grains
1	16	5·5	0·3	4·6
2	22	5·5	0·4	6·2
3	26	5·5	0·54	8·3
4	28	6	0·65	10·0
5	30–32	6	0·8	12·3
6	35	6	1·0	15·4
7	40–45	6	1·5	23·1
8	50–55	6–7	2·0	30·9
9	—	—	2·5	38·7
10	—	—	3·0	46·3



No. 5 No. 6 No. 7 No. 8

FIG. 26. Detonators

The numbers in common use are 5 to 8. They are filled with pure fulminate, or fulminate mixed with 10 to 20 per cent. of chlorate of potash.

Detonators are also made with composite charges. First a charge of trotyl or tetryl is introduced into the detonator tube, then a small quantity of fulminate, over which is placed a "reinforcing cap" which gives it extra confinement, and the whole is compressed.

Tetryl is the trade name of tetranitro-methyl-aniline, and is often re-

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ferred to in the British Service as C.E. (Composition Exploding).[1] It is made indirectly from benzene, which is first nitrated to nitro-benzene $C_6H_5.NO_2$, and then reduced to aniline $C_6H_5.NH_2$. This is converted into methyl-aniline, $C_6H_5.N(CH_3)_2$, which on nitration yields tetranitro-methyl-aniline $(NO_2)_3.C_6H_2.N\begin{smallmatrix}CH_3\\NO_2\end{smallmatrix}$. It is a pale yellow crystalline substance melting at 130°C., somewhat more sensitive than trotyl or picric acid.

For the ignition of the detonator or, in the case of blasting explosives of the black powder class, for the direct ignition of the charge a fuse of one sort or another is used. This is a device by which a flame is communicated to the detonator or charge either after an interval of time, or by an operation conducted at a distance. In either case the shot firer is not exposed to the effects of the explosion.

Safety fuse consists of a narrow core of black powder surrounded by layers of jute thread and fabric. A great many varieties of safety fuse are made, differing principally in the number and character of the layers of covering material, and in the waterproofing applied, if any. In England it is sold in coils of 24 feet, but in America they are 25 or 50 feet long, and on the Continent 10 metres (about 33 feet). In Germany the fuse is coloured to distinguish the different manufacturers from one another, but in England a further distinction is made by varying the colouring of the different varieties.

Regularity in burning is the first requisite of safety fuse : usually it is made to burn in the open at the rate of about 30 seconds per foot or 100 seconds per metre. Interruptions in the continuity of the thread of powder will prevent the ignition of the charge, and so are dangerous. They may be detected by examining the fuse under X-rays.

More primitive igniting arrangements are still used in some mines and quarries, where stringent regulations are not in force. One device is the miner's squib (Fig. 27), which consists of a tapering paper tube about 7 inches long, filled with fine gunpowder. One end of the paper tube is treated with chemicals so as to form a slow-match, which when ignited takes so long to burn that the miner has time to reach a place of safety before the explosion. When used the squib is placed in the needle hole, or blasting barrel through the tamping with the match end of the squib outward. When the match is lit, it burns slowly until the flame reaches the powder core ; then the squib darts forward like a rocket, leaving a trail of flame behind, which spurts out of the needle hole, and the flame burns rapidly through the squib and bursts out at the other end of the tube, and so ignites the charge.

Quick-match was formerly used for igniting charges both in military and civil blasting ; it is still used in making up fireworks, etc. It is made of

[1] See official communiqué in *British Medical Journal*, December 16, 1916.

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cotton wick boiled with a solution of mealed powder and gum, and afterwards, before it is quite dry, dusted over with mealed powder. It may also be made by soaking cotton thread in an alcoholic solution of gum and then dipping it in gunpowder. Unenclosed, it burns at the rate of a foot in about four seconds, but if enclosed in a tube, it burns much more rapidly.

Instantaneous fuse consists of several strands of quick-match enclosed in a wrapping of waterproof tape: its speed is from 100 to 300 feet per second. Formerly it was much used in extensive blasting operations, where a number of charges had to be fired simultaneously, but it has now been superseded by electric detonators and detonating fuses. It was fired by means of a percussion cap in a special pistol.

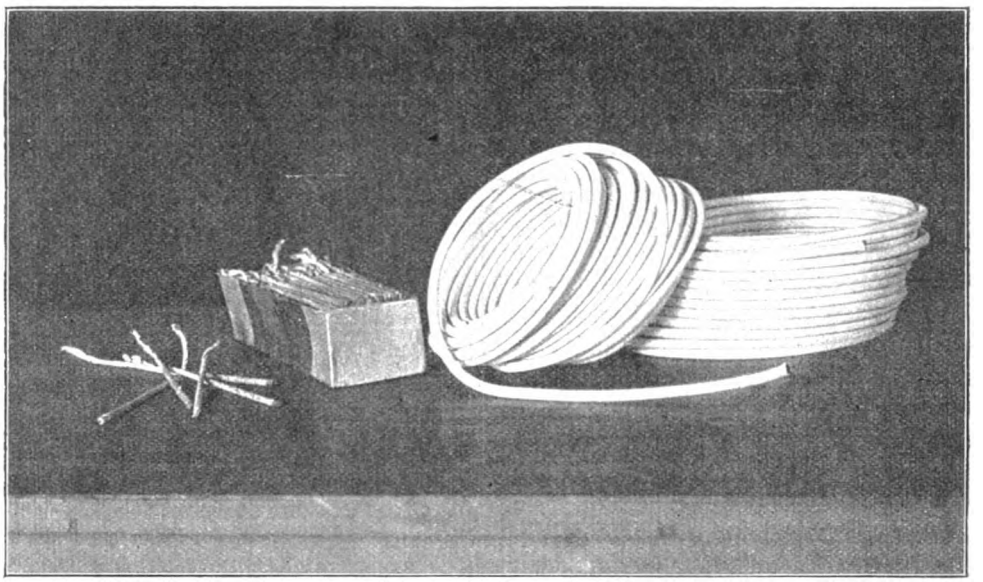

FIG. 27. Squibs and Safety Fuse

Slow-match is made by boiling loose hemp cords in a dilute solution of saltpetre; it smoulders away at the rate of a foot in several hours; it is used when a long delay is required.

Detonating fuse is made by filling lead pipe with trotyl and drawing it out. When fired with a 2-gramme detonator it detonates at the rate of about 6,000 metres per second. It can be used to detonate a number of charges simultaneously.

The development of electrical science and industry naturally led to the idea of firing explosives by means of an electric current. Heat generated

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by a current is utilised to fire a suitably constructed fuse, and this ignites a detonator, which in turn explodes the charge. Much ingenuity has been devoted to the designing of electric fuses, but they may be divided into two main classes: high and low tension fuses. In the former a spark is made to pass between two metal poles and ignite a priming material such as a tuft of guncotton, or a mixture of potassium chlorate and antimony sulphide. In the low-tension fuses there is a small bridge of fine wire generally made of platinum, and this is heated to incandescence by the current, thereby igniting the priming. The fuses now used are nearly always of the low-tension type: one of the advantages that they possess over the other type is that each fuse before use can be tested as to the resistance that it offers to the current, whereas a high-tension fuse can only be tested by firing and so destroying it. When testing the resistance of a low-tension detonator it should always be inserted in a safety receptacle so that, if it should fire, no harm will be done.

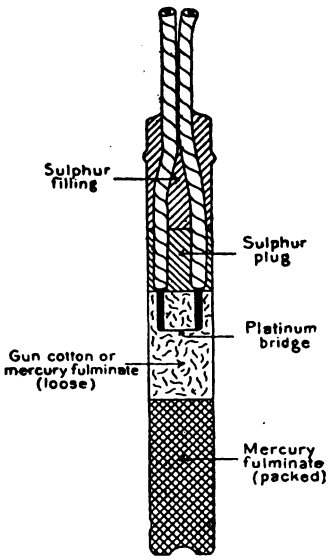

FIG. 28. Electric Detonator (From *U.S.S. Bureau of Mines Bulletin*, No. 80)

For firing charges of explosives of the gunpowder type, electric igniters can be used similar in construction to electric detonators, except that the capsules are made of paper or wood instead of copper and are charged with a gunpowder mixture instead of fulminate.

Fuses can also be made that are fired by mechanical action as, for instance, by pulling a wire or cord, which releases a striker which is driven by a spring on to a percussion cap. Such devices are but little used, however, except for fuses for firing artillery shell.

There are two main varieties of fuses for shell, namely, percussion and time fuses. The former may be fixed into either the base or the nose of the shell: in either case they generally work on the same simple principle: when the shell strikes an object the sudden retardation either causes a pin to strike a percussion cap or makes the cap fall on to the pin; but in some cases nose fuses are so made that on striking the object a strong diaphragm is forced in, so driving a needle into a percussion cap. The flash from the cap ignites some priming composition, and so the ignition is communicated into the interior of the shell proper. The fuses may be provided with a delay arrangement, a small pellet of combustible matter, which must be burnt through before the flame can reach the shell. This causes the shell to explode only after it has passed through the object struck, the armour plating of a ship for instance.

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The fuse must, of course, be so constructed that the shell is not exploded prematurely in the gun, nor by such blows as it may receive in handling and transport. The moving part is therefore held in place, usually by a spring which can only be overcome by a severe blow on the nose of the shell. In the case of shell filled with high explosive, the result of a premature detonation in the bore of the gun would be so disastrous, that special safety arrangements

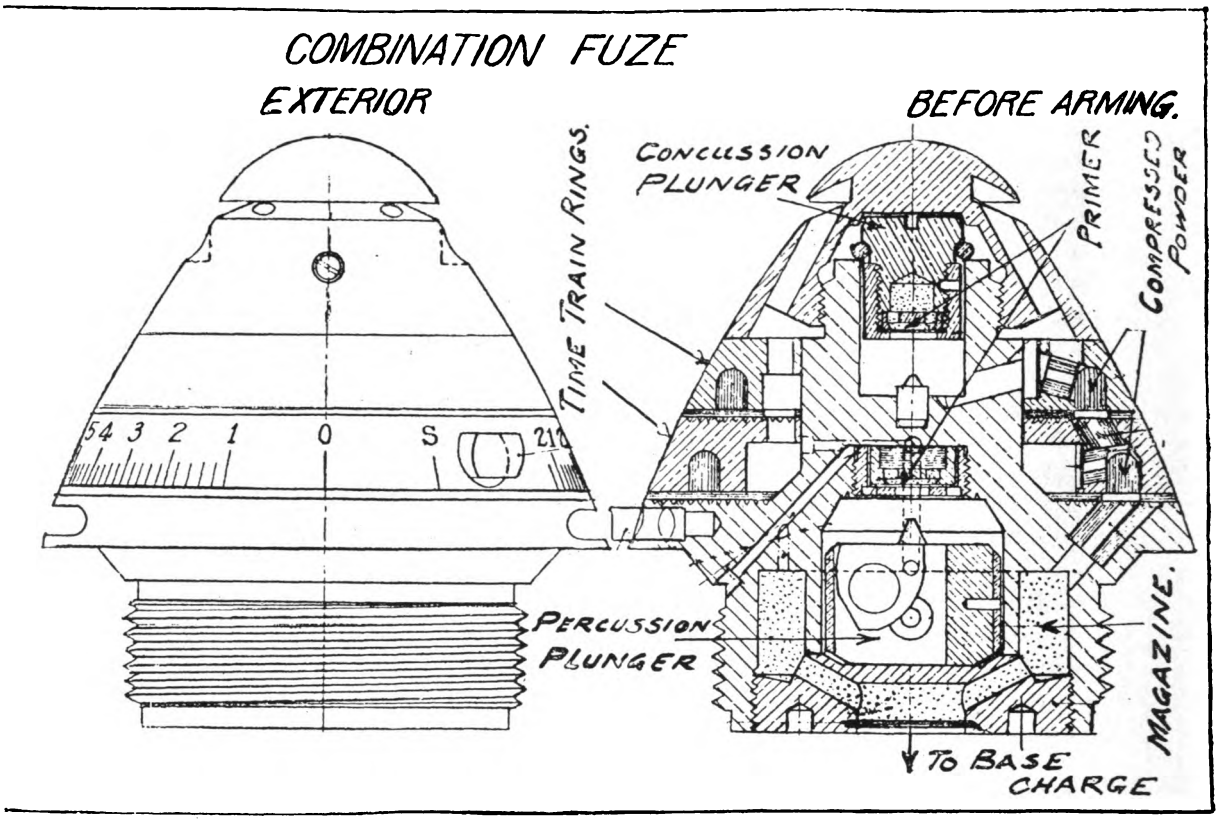

FIG. 29. Time and Percussion Fuse
(From Major O'Hern's paper in *Smithsonian Report*, 1914, pp. 249–275)

are generally introduced. The percussion cap is entirely cut off from the interior of the shell until some disc or shutter has been removed, either by the pressure of the powder gases on the base of the shell or by the centrifugal force caused by the rotation of the shell.

Time fuses are used mostly for shrapnel shell, which is required to burst shortly before it reaches the object shot at. But, as a rule, the fuse also

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contains a percussion arrangement, so that, if the time mechanism does not function, the shell will still be exploded when it strikes, and so may be of assistance to the artilleryman in gauging the range, even if it does no damage. Time fuses are always fixed to the nose of the shell. The primitive fuses used in the early days were made to ignite by the flame of the powder charge, but now the concussion of the discharge is utilised to fire a percussion cap. Before the flame can reach the bursting charge it has to burn through a lengthy column of comparatively slow-burning gunpowder composition, generally placed in one or more movable rings. The gunner by twisting one of these round can alter the length of the column to be burnt through, and consequently the range at which the shell will burst. The construction of time and percussion fuses is shown in Fig. 29. Each ring has a circular slot cut in it nearly all the way round filled with compressed gunpowder : it is ignited at one end and the flame travels round until it comes to the hole leading to the next ring or the priming.

The French have developed a time fuse in which the time composition is contained in a spiral tube. It is set by stabbing this tube in the correct place. This fuse has the advantage that the time composition cannot become moist by exposure to the air, and very long times of burning can be arranged for, whereas with the ordinary time ring arrangement it is difficult to make the fuses burn more than about 24 seconds.

The powder in a small-arm cartridge is fired directly by the flame from the cap, which is ignited by the blow of the striker upon it ; but a cannon cartridge requires also to have an igniter of some easily fired explosive such as gunpowder, as the flame from a cap or tube is quite insufficient to ignite smokeless powder of large size with regularity.

For firing high explosives use is made of a detonator, which is fired by means of a fuse. Most commercial explosives are made to detonate with a detonator containing not more than 2 grammes of fulminate of mercury, but gelatinised nitroglycerine explosives, such as blasting gelatine, are much more violent if a primer of an ungelatinised explosive, such as dynamite, be used as well. For many naval and military purposes much less sensitive explosives are required, and these can only be detonated with certainty by means of a priming of some other powerful, but more sensitive explosive. Wet guncotton, for instance, is generally fired by means of a priming of dry guncotton, which in turn is exploded by a detonator (*see* Fig. 8). Picric acid when cast or compressed to a high density is almost as insensitive as wet guncotton : it is often exploded by means of a priming of picric powder, a mixture of ammonium picrate and saltpetre, or pellets of trotyl or tetryl may be used provided they are only compressed to a comparatively low density. Large fulminate detonators are therefore generally avoided, although they have been used by some of the Continental armament firms. When detonators are not used, it is

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necessary to have a priming that will burn to detonation when ignited by a small charge of gunpowder only. This priming is sometimes placed separately in a cavity formed in the middle or on the top of the charge in the shell; sometimes it is in a metal sheath or "gaine" attached to the bottom of the fuse. Use may also be made of a comparatively sensitive explosive, such as tetryl, which is exploded by means of a small fulminate detonator.

It is not very easy to ensure the satisfactory detonation of shell filled with insensitive explosives, especially in the case of the smaller sizes of shell. The detonator and the exploder must be of sufficient strength. The intermediate explosive, or exploder, must be moderately sensitive and must be in close contact both with the detonator and the main charge of high explosive.

If the whole of the charge is not consumed in the explosion, the shell is said to "explode" instead of detonating. An "explosion" is revealed by the colour of the smoke that appears when the shell opens. If there be an unconsumed explosive the smoke will be more or less of the colour of the explosive, generally yellow. If the explosive be entirely consumed the smoke will be white or black according as it contains sufficient oxygen to oxidise the whole of the carbon present or not. The violence of the detonation can also be judged by firing a shell at rest in a closed chamber lined with steel plates and ascertaining the number and size of the fragments into which the shell is broken (*see* Fig. 11). This, however, is not considered so satisfactory a test as firing from the gun at a steel plate or other target, according to the nature of the shell. With practice the observers can form a good estimate of the violence of the explosion or detonation.

Many explosives do not detonate completely unless they are strongly confined, but even if they can be detonated in the open they produce much greater effects when confined. In a shell the steel walls provide the necessary confinement. When carrying out demolitions the explosive should always be covered with a thick layer of earth or other material, if practicable. In mines and quarries the explosive is usually placed in a hole bored into the rock. The weight of the charge should be just sufficient to break through the surrounding layer of rock. After inserting the charge it should be stemmed or tamped by putting in clay or sand, and ramming it home firmly, so that the force of the explosion may not be wasted by just blowing the stemming out.

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CHAPTER XI

PRECAUTIONS

In order to minimise the risks of explosions in factories where explosives are made or dealt with, constant care and numerous precautions are necessary. Only some of the most important of these can be dealt with here.

The workers should be provided with special clothing without pockets or metal buttons. As there is nearly always a considerable risk of fire, as well as of explosion, the clothing should be made of wool, or of cotton specially treated to render it non-inflammable. If used in dusty operations the clothes should be washed periodically. These clothes should be worn in the factory only, and provision must therefore be made for changing them. Matches, pipes and other dangerous articles must not be taken into the danger buildings and the workers should be searched to make sure that this regulation is being kept.

Danger buildings are usually constructed of light materials such as wood, or preferably fireproof sheets on wooden framing, so that, if an explosion should unfortunately occur, not much heavy débris is thrown about. Floors may be of wood, but are better if covered with linoleum. Asphalt is to be preferred if well laid. In nitrating buildings and nitroglycerine houses the floors are generally covered with lead. Inflammable materials are to be avoided, for a fire spreading may cause a disastrous explosion. Combustible articles, such as packing-cases, should be cleared right away from the danger buildings.

The use of implements made of iron and steel is usually forbidden altogether. Where their use is unavoidable they should be restricted to certain houses and operations. The number of implements of any sort should be kept as small as possible. The quantity of explosive and number of workers allowed in a building are rigidly limited, and are posted up on a board at the entrance. The lighting must of course be adequate, but direct sunlight must not be allowed to enter. For artificial light electric lamps are used mounted inside strong glass globes. Doors should open outwards and, if the building be large, there should be at least two.

At the door there should be a barrier about a foot high, and here the shoes

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should be changed, or overshoes should be put on, to prevent grit being carried into the buildings.

Picric acid presents special difficulties because it forms sensitive compounds with many materials, especially with iron, lead and lime. The buildings in this case should be painted with zinc white and the only metals used in contact with it should be aluminium and zinc.

Magazines are generally made of strong construction. Armoured concrete has been much recommended. Otherwise the rules are much the same as for other danger buildings. Armoured concrete has also been proposed for the manufacturing buildings.

The precautions taken must depend on the nature of the materials dealt with. Fulminate and other very sensitive explosives must be treated with special care, and the quantities in any one place kept very small. Wet guncotton, on the other hand, is almost safe, and many of the usual precautions can be omitted in houses where no other explosive is present.

The U.S. Bureau of Mines has issued the following warnings concerning the treatment of explosives in magazines:

Don't store detonators with explosives.
Don't open packages of explosives in a magazine.
Don't open packages of explosives with a nail puller, pick or chisel, but with a hard wood wedge and mallet outside the magazine and at a distance from it.
Don't store explosives in a hot damp place.
Don't store explosives containing nitroglycerine so that the cartridges stand on end.
Don't repair a magazine until all the explosives have been removed from it.

The buildings should be so far separated from one another and from other houses that in case of an explosion the effects will be confined almost entirely to the one house. The minimum distances are prescribed in official regulations in most countries. If high mounds are erected around the danger buildings the distances can be diminished to about half what should otherwise be necessary, as they cause the principal effect of the explosion to be diverted upwards. Explosive factories should be erected away from houses and villages.

It is a general rule that danger buildings be provided with lightning conductors. These should not have turns and twists in them, otherwise they will, in the case of a severe lightning stroke, lead the lightning into the building instead of away from it. The best form is a high metal mast near the building. This may be made of steam piping with a copper point at the top. Even this is not always effective in localities liable to bad thunderstorms, and the only safe method of building nitroglycerine factories in such places seems to be to place them underground.

Nitroglycerine is liable to freeze if the temperature falls below about 56°F. (13° C.), and when solid is more sensitive under certain conditions and cannot be worked until it has been thawed again. Nitroglycerine houses must

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therefore be kept above 56° F. in winter. In use frozen nitroglycerine explosives present various dangers. They must be thawed, therefore, by placing them for a time in a can with a double wall having hot water in the outer casing. It is better, however, to prevent the explosives freezing by keeping the magazines warm.

Nitrocellulose and nitroglycerine decompose gradually on keeping even at the ordinary temperature, and at higher temperatures the rate of decomposition increases rapidly. In decomposing they form acid substances that accelerate the decomposition, which under some circumstances may become so rapid that the explosive may ignite or explode. There are many cases of such spontaneous ignition of smokeless powders on record. These explosives should therefore be kept cool, and the magazines of warships are usually provided with refrigerating plant to keep the temperature down. Nitroglycerine high explosives present the same danger. In order to prolong their lives substances are usually added to these explosives to destroy or combine with these acid bodies. High explosives usually contain a small proportion of carbonate for this purpose. Smokeless powders also generally contain a little calcium carbonate (chalk), but in addition nearly always have a little of some stabiliser, such as diphenylamine or mineral jelly.

The powders must be examined and tested periodically to ascertain that they are not getting into a dangerous state. For want of such precautions in the past a number of battleships have been blown up, and magazines have been destroyed. The tests available for the examination of these powders are not very satisfactory, as their indications are wanting in certainty and precision, but if they are applied with adequate knowledge and careful records are kept of the past history of the powders, the risks are almost eliminated.

In the Abel heat test a small quantity of the ground-up explosive is placed in a test tube in a heated water bath, and from the top of the tube is suspended a piece of paper impregnated with potassium iodide and starch and moistened with a mixture of glycerine and water. After a time a brown line forms on the paper, and if this appears too soon the powder is condemned. In other tests the powder is heated at various temperatures and the loss of weight is ascertained after a fixed time, or the volume of gas evolved is measured, or the time is observed before red fumes are given off. It has also been proposed to extract the diphenylamine or other stabiliser and examine it chemically to ascertain whether it is still active. This last method, although promising, has not been in use sufficiently long to show whether it is reliable.

The vapours of ether, alcohol, benzene and toluene used as solvents and in the manufacture of explosives are injurious, and rooms where they are exposed should be provided with good ventilation.

The nitro-derivatives of the aromatic hydrocarbons are decidedly poisonous, although not very volatile. Dinitro-benzene and dinitro-toluene are liable

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to be absorbed through the skin, and also as dust or fumes, causing skin eruptions, anæmia, breathlessness and headaches. Trinitrotoluene (trotyl) does not appear to affect the blood and general appearance of the sufferer as much as dinitro-benzene, but after a time it attacks the liver causing jaundice, which in some cases has proved fatal. Workers under twenty years of age are particularly liable to be affected, and those who take much alcohol are also said to suffer from the effects of these substances. Buildings in which these explosives are dealt with should be well ventilated and provided with extract fans which draw the dust and fumes away from the workers in a downward direction. The workers should be examined medically before starting this work and weekly afterwards. Those who are affected should not work with trinitrotoluene continuously for more than a fortnight at a time, and should then be put on to some other work for a fortnight before returning. Special clothing should be provided for use in the workrooms only, and should be washed frequently. A pint of milk is usually provided for each worker before starting work. Meals must of course be taken in a separate place, and the hands and the face should be washed before eating. Investigations are being made to ascertain whether special benefit is obtained by washing with solvents such as acetone, benzene or a dilute solution of caustic soda in alcohol.

It is apparently the trotyl that is absorbed through the skin which is specially injurious, rather than that which is inhaled. It then passes in a combined form into the blood, and in some cases is eliminated from the system only very slowly.

Tetryl (tetranitro-methyl-aniline) does not appear to be so injurious as trotyl, but it has not been made on nearly such a large scale. Picric acid has been manufactured and used very extensively for many years, but does not seem to have had injurious effects on the workers, except to cause local sores.

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